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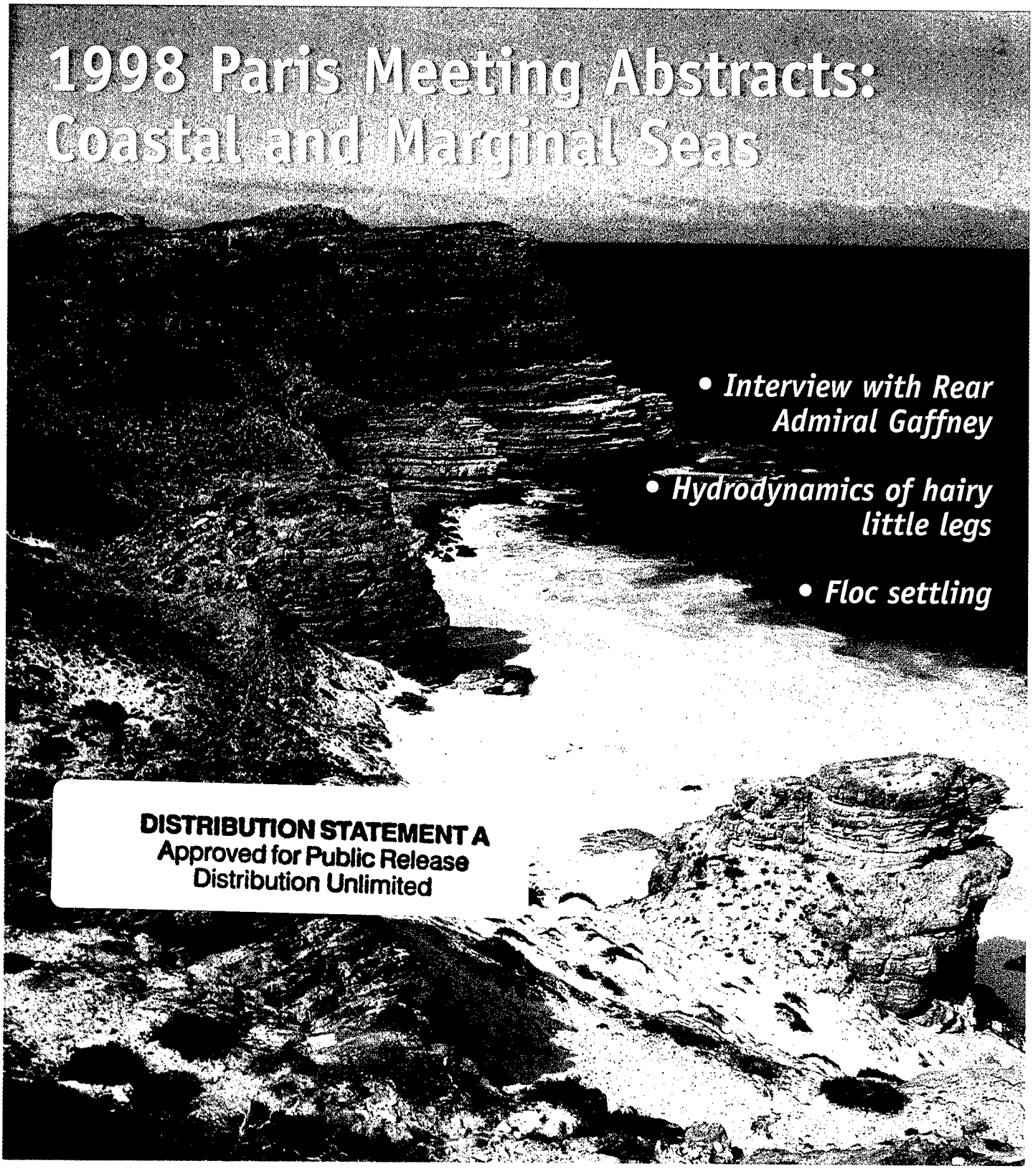

1998 Paris Meeting Abstracts: Coastal and Marginal Seas

- *Interview with Rear Admiral Gaffney*
- *Hydrodynamics of hairy little legs*
- *Floc settling*

Nominations for the Walter Munk Award

In January 1999, the Walter Munk Award Selection Committee, made up of representatives designated by The Oceanography Society, the Chief of Naval Research, and the Oceanographer of the Navy, will begin reviewing nominations. If a worthy candidate is identified, the fifth *Walter Munk Award for Distinguished Research in Oceanography Related to Sound and the Sea* will be presented at The Oceanography Society's April 1999 meeting in Reno, Nevada.

In keeping with Professor Munk's contributions to ocean science, nominations for the award will be based upon:

1. Significant original contributions to the understanding of physical ocean processes related to sound in the sea;

2. Significant original contributions to the application of acoustic methods to that understanding; and/or

3. Outstanding service that fosters research in ocean science and instrumentation contributing to the above.

Previous awardees include:

Walter Munk, 1993
David Farmer, 1994
Steven Thorpe, 1996
Leonid Brekhovskikh, 1996

Nominations for the award should be forwarded by February 15, 1999 in writing to:

THE OCEANOGRAPHY SOCIETY
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13. ABSTRACT *(Maximum 200 words)*

This grant supported a successful international multidisciplinary scientific meeting addressing the topic "Coastal and Marginal Seas," hosted by The Oceanography Society and UNESCO's Intergovernmental Oceanographic Commission in Paris, June 1-4, 1998. The meeting attendance was 237 total with paticipating scientists from 33 countries. 160 abstracts were accepted for presentation as either as a plenary talk or a poster. The topic was covered in depth from small scale processes to regional scale processes to a global perspective. Partial reimbursement of travel expenses of invited speakers was also made possible through this grant. Without such support, attracting leaders in the field would have been severely restricted. Publication of a special issue of "Oceanography" magazine containing the submitted abstracts was also supported by the grant. Publication of the abstracts in this vehicle makes them citable references which is extremely important to authors and increases their ong-term value to the scientific community. This meeting and the publication of the abstracts facilitated communication and exchanges among scientists from the global ocean sciences community.

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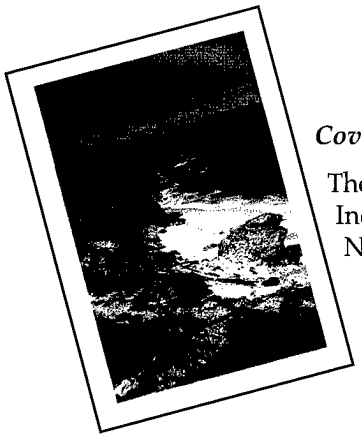

Cover Photo:

The rocky shore of the South African Indian Ocean coast at Tsitsikamma National Park (photo by R. Spinrad)

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Quarterdeck

Richard W. Spinrad, Editor

The view from the Quarterdeck is gorgeous. As I take the helm from our previous Editor, Larry Atkinson, I'm enjoying a vessel well cared-for and a course well-set. The rich history of this magazine presents a somewhat daunting legacy. It is upon that heritage that I hope to build an even broader audience. *Oceanography* has become much more than the society magazine originally intended. Most members of The Oceanography Society have kept their full set of back issues and treasure the collection as a resource for teaching, entertainment and general reference. The TOS Council is, as we speak, acting to post back issues of the magazine on the World Wide Web, for even broader distribution. Aquariums have asked for copies of previous issues to sell in their bookstores. What a testimony to the skills and dedication of my predecessors and their long list of contributors.

With this volume, dedicated to the 1998 Paris meeting on coastal and marginal seas, we'll take that legacy and move even farther. When I was first approached by the TOS Council to consider editing the magazine I made them an offer I was sure they would refuse: I would serve as editor if they would let me implement several changes to the magazine. These changes aim at preserving the high technical and aesthetic quality of *Oceanography* while broadening the audience. *Oceanography* should be the oceanographic equivalent of *Scientific American*, without the ephemera, and without any crass advertising. *Oceanography* should not only be read by our membership, but it should be the resource of first choice for educators (at all levels), policy developers (at all levels), the techno-media, and the scientific literati. Want to know about El Niño? Curious about toxic algal blooms? Need to understand the basics of ocean color remote sensing? Check *Oceanography*. But there's even more. *Oceanography* should have its finger on the pulse of the community. The magazine should be a source of new ideas, an indicator of trends and a think-tank for discussions. Some of this new approach is already evident in this issue: we've included our first interview with one of community's most influential leaders, the Chief of Naval Research, Rear Admiral Paul G. Gaffney, Jr.

So step on board and enjoy the cruise. The mid-life refit is complete. As you can see from this volume, the ship's hold is full, the tanks are topped off, and — stretching the analogy even further, in terms of the new appearance of the cover and text style — we've even repainted the hull and decks. *Oceanography* is ready for its next grand journey!

The National Ocean Conference

Kenneth Brink

In recognition of Vasco da Gama's great voyage from Portugal to India, 1998 was designated by the United Nations to be the International Year of the Ocean. Globally, the year has been marked by events such as the Lisbon World's Fair. Most prominent among the numerous United States activities has been the National Ocean Conference, held in Monterey, June 11-12. Many academics probably know little about the event or have much concern about what was accomplished there. It was nonetheless an important occurance, and worth a bit of closer consideration.

The National Ocean Conference was meant to be a forum to pull together the academic, governmental, environmental and business sectors that have an interest in the ocean. There were initial parallel half-day sessions to consider issues such as exploration and research, fisheries, and national security. These were followed by a plenary session where the results of these groups were discussed with the Vice President, and by a second day where a number of political figures, including the President himself, gave speeches about the ocean. With hundreds of people in attendance, and time for truly open discussion limited, it is fair to say that no issues could be treated in much depth. Of the four sectors represented at the meeting, the environmental ("green") organizations were clearly the most visible, and the business sector was probably the least visible. As an academic, I had always had the feeling that the main people interested in the ocean were scholars, governmental people (including the Navy) and a scattering of fisheries people. It was a major awakening for me to see how large and strong a voice the environmental community represented.

One could ask what sorts of results were obtained at this meeting. A number of funding initiatives were announced, although it was not very clear to what extent these represented genuinely new undertakings, as opposed to simply announcing projects that would have happened in any case. A showpiece moment was when the President declared further moratoria on offshore oil drilling, but this was not something that was of much scientific substance either (although the local political effect was likely substantial). Instead, what was really important about the meeting was simply the good feelings, and the fact that for at least a while, the attention of our national leaders was genuinely focused on the Ocean. This in itself represents a wonderful start in gaining national attention for the ocean sciences, and each of us, in his or her way, can now help to exploit this momentum to improve the visibility, status and effectiveness of the field.

This special issue was made possible by the U.S. Office of Naval Research.

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Interview with the Chief of Naval Research

Richard W. Spinrad

***Oceanography* Editor, Rick Spinrad, interviewed the U.S. Chief of Naval Research, Rear Admiral Paul G. Gaffney, Jr., for this special issue, which was sponsored by the U.S. Office of Naval Research. Admiral Gaffney, himself an oceanographer, has also commanded the U.S. Naval Meteorology and Oceanography Command in Mississippi and the U.S. Naval Research Laboratory in Washington, D.C.**

Oceanography: **The first question deals with the Office of Naval Research's (ONR) support for The Oceanography Society: sponsorship of conferences, special issues of the magazine, and the Munk Award. Why has ONR shown such support for TOS?**

Gaffney: We believe that the Navy and ONR have a leadership responsibility in the US for oceanography. It is a core science, it is, of all sciences, the naval science and we have a responsibility to make sure that the national investment and our investment supports the needs of the Navy and likewise the needs of the nation. So it is important for us to do whatever we can to keep the general ocean scientific area strong and healthy. It would not be unusual that we would focus on oceanography in general. Supporting TOS and its magazine is a way of articulating our leadership, our interest in the ocean, and giving back to the American taxpayer whatever we can. The fact is, it's the American taxpayer's money that we spend, and whenever we can return that to him in some useful way directly, we should do that. And it is often returned in ways he doesn't know, because it gets engineered into systems, or engineered into certain kinds of knowledge that is used by the scientific community, but when it can go back in other ways, in the largest and most prosperous maritime nation of this planet, then we should do that. This magazine is the proper vehicle for doing just that. In fact, most of what we invest in shows up in some kind of a journal. TOS however, tries to reach other parts of society, beyond the "heads down, looking at the bench" scientist. You reach members of Congress, industry, educators, and all of that is part of letting people know what we're doing and giving back to them some of the investment that they've made in us.

Oceanography: **Is there anything that you could refer to as "feedback" or "product return" for the support of TOS? Anything specific that comes back to ONR or the Navy as a result of TOS sponsorship?**

Gaffney: Some of the conferences in which we are the principal supporter tend to focus talent in areas of special interest to us. While it seems altruistic, we are a bit selfish in that when we put hard cash on the table, we want to make sure that there is a direct return on something very specific that we're after. Like the conference in Paris. Dealing with coastal and marginal seas is of extreme interest to the U.S. Navy which right now, recognizes this as the most difficult environment for them to operate in. Having the conference in Europe and focusing on the area is one thing, but then having the conference in a setting in which there are many nations interested in only coastal and marginal seas, because that is the environment they live in I think is double-bang for the buck. So we were very happy to sponsor the Paris conference and get that kind of interaction going. Our principal investigators were able to talk with others; to get ideas put on the table that they normally wouldn't have had the opportunity to do so.

Dealing with coastal and marginal seas is of extreme interest to the U.S. Navy which right now, recognizes this as the most difficult environment for them to operate in.

Another example might be the Munk Award, which focuses on acoustics. Oceanography is a core, naval science. Within oceanography, acoustics is even more so, and ONR has the [U.S.] national responsibility for acoustics. While other agencies certainly do invest in acoustics projects, if we/ONR would pull out altogeth-

er, it would collapse and so we are very interested in that role. When we find mechanisms to advertise that we are still actively interested in acoustics, we're still supporting it for the long term, and how important it is–we highlight that impression by having this award, [honoring] perhaps the most prestigious living oceanographer, Walter Munk. It shows people our interest and dedication to the subject. This year, in fact, we've examined this award very closely and are fine tuning our program a little bit with some additional resources to make sure that the national program regains some lost help.

Oceanography: **You started to address the specific issue of why the coastal and marginal seas meeting was conducted in Europe. This approach, at least in the oceanographic community, was somewhat unusual in terms of U.S. sponsorship. Would you categorize the Paris meeting as a success and as the kind of thing you would like to do in the future, as a focused subject in a venue not necessarily in the U.S.?**

Gaffney: When you're looking at priorities, contemporary issues, focusing on getting something out of it that is useful, rather than just having a clambake so that people can exchange ideas, putting it in the right venue is important. Was the right venue overseas? Sure. Putting it overseas just because it is a nice place to go is never a reason. If there is a good reason to do it overseas, we should do it overseas.

Oceanography is a core naval science.

Oceanography: **The subject matter, coastal and marginal seas, is one which people may have interpreted as "the U.S. Navy is no longer interested in blue water oceanography." How do you address that statement?**

Gaffney: What we've said is that we have to have a balanced program that still has a deep-water component. Approximately 40% of the work we do is deep-water related, 40% is shallow-water related, and 40% is everything. Now I know the arithmetic does not add up, but there are certain techniques like some modeling, some remote sensing, some instrumentation that span all regimes and some don't. But we seek a balance. We are trying to recognize something that has not been recognized in the past, that there is a real challenge in the shallow water, the oceanographic challenge, and we also know that the challenge is congruent with the challenge that the Navy and the Marine Corps face.

Oceanography: **Along those lines, what are the priorities for oceanographic research within the Navy?**

Gaffney: I guess you could characterize it two ways: by discipline or by the actual use of the knowledge that is gained. Let me try the latter, and I would say that right now the number one issue, the one that we cannot blink from, the one that we have ignored, as a corporation have ignored the most in the past 15 years is mine countermeasures. Being able to search and identify and find ways to avoid them is almost exclusively a shallow-water issue. It is the ultimate asymmetric warfare technique.

Oceanography: **What do you mean?**

Gaffney: Asymmetric, meaning a very cheap tool can be used to defeat a very powerful enemy, with expensive systems. Virtually anybody can use these in any place in the world. Typically the mines are in shallower waters, protecting harbors, or certain waterways that are important to them. This is the number one issue in the world today. And that is where we are putting our most emphasis.

There are other areas that are of equal importance: anti-submarine warfare has historically been a top priority for the Navy. It still is a priority, less than mine warfare right now–but many of the techniques we use as oceanographers, to address the mine warfare threat, are equally as useful in the shallow water, anti-submarine warfare. And so whenever we can make that trade, with the application, we do. But it also affects the things like special operations, like amphibious landings which typically come after the mine warfare issue is solved. The interaction of the oceans with the atmosphere in the coastal regime is very complicated, and that affects our ability to conduct air operations, whether they be with manned or unmanned aircraft. The interaction of the oceans and the atmosphere also has a great deal to do with the safe passage of ships and the ability of the people on those ships to function. Knowing when to avoid, or take advantage of bad weather is important. So it is really impossible to draw the line and say this is the only application this research affects, because as you understand the maritime environment it applies to all of them–we are putting a little bit more emphasis on mine warfare now, and in my opinion should have in the last 15 years.

Oceanography: **As a consequence, are program managers more inclined to put their money on safer bets, or do you see a risk level that's allowable in sponsored research? Are we seeing a more conservative sponsorship of research?**

Gaffney: I have great faith in the people at ONR. I find them a rather (now this is a compliment) irreverent group in that they try to stick to the high ground.

I will say that I am generally concerned that 20-30 years of decreasing funds for basic and applied research will tend to design work that does not require a great deal of overhead. "Overhead," to me is going to sea and doing things from ships as opposed to doing everything from a PC or a terminal hooked to a supercomputer

someplace. We could completely consume this community with theoretical modeling, or simulation work, fully employ them all and never go to sea. We could also employ everyone at sea and never do anything else. I worry that nationally and in the Navy in the long term, as money continues to go down, people look for opportunities where overhead is less, to keep people working at the bench. I can't point to incidences, but I am worried about having some difficulty filling up all of our ships right now, even though, as anyone can imagine, there are thousands of years of work to be done at sea. A wise man recently told me that every time you go to sea, you find something you did not expect that you should go back and investigate. That's one of the differences between oceanography and other fields. I am concerned about that, nationally and for the Navy.

Oceanography: **If we, for argument's sake, assume that money will not be the sole driver for how research is done in the future, that is to say that there is some stability in funding, what do you see happening fifty years down the line in the way ocean research is done?**

Gaffney: I foresee our increased ability to handle, store, and to manipulate data–and there should be a lot more data, nationally and internationally–that can be moved around to solve peoples' problems.

I think in the fifty-year time frame, we will still be using ships, however we will be using those ships much better--as in "less risk." When you send them someplace you will know what they actually are going to do. I see a combination of using ships with remote sensing techniques, real-time linkups, and widening the aperture of ships-or eliminating ships using uninhabited, undersea vehicles (UUV). UUV will also be a way to increase the aperture of a ship, if you are going to use a ship, or not use a ship when you don't have to, because ships are expensive with people on board. Using satellites, remote sensing techniques, buoys, over-the-horizon radars, instruments on airplanes, commercial airliners, ships of opportunity and all those kinds of things will, likewise, reduce the need for ship time. I am not one that would define away a ship, however. I still think that you have to go out there occasionally and look over your spot. I can't imagine ODP (Ocean Drilling Program) being replicated through UUV over the next 50 years. If you want to look below the surface, you probably still have to do that from some vessel that floats on the top.

Oceanography: **Actually the Ocean Drilling Program is a good way to come back to the question of funding, in the terms of its being an international program. You've established this scenario for fifty years down the line, given that we have a current national and international funding structure. Will that work for the kinds of objectives you've stated for the future, or are we looking at a different way of supporting oceanographic research?**

Gaffney: I guess I don't envision a big budget meeting where 50 nations get together in a room and put together a master plan for the global oceanography program except for some discrete, international programs. But the whole program, I don't see being coordinated well by some international body. I can see coordination between communities, among scientists, on an individual level and for some discrete experiments that can be orchestrated and bureaucratically handled. I'm sort of a decentralization-guy. I would prefer that international collaborations be made up of the scientists themselves, by picking the right partners because they know what is going on, rather than some bureaucratic body, who by its definition becomes detached from the science and doesn't get its feet wet or its hands dirty trying to legislate where dollars go. That worries me.

But there is another way for international cooperation/coordination to occur in discrete areas, and that is by increasing involvement in industry, which is gradually becoming more international. I would hope that industry is a very interested partner in TOS and an increasingly important partner in TOS, because the big parties that can afford to go out to sea are international, and they *can* make things happen as well.

Oceanography: **So you see them as catalysts, not necessarily the leader for international cooperation?**

Gaffney: Not necessarily the leader, maybe in certain areas they could be the leader. Certainly in the resources, geology/geophysics area they could be leaders, sure, and I have no problem riding along with them and making partnerships.

It is sort of a theme that we have at ONR, and I have not really tried it in oceanography, but if I really thought about it, I could. I've been worried about the dwindling money going out to academia over the years. And I'm also worried about money going out to industry. I'd like to see the two get together-the basic research community, which includes some small percentage of government laboratories and industry. In my opinion, industry doesn't put money into basic research, and so their vision is unofficially truncated at the level of product development-they don't look 30-40 years down the line (there are some exceptions). And the universities, while they may look down the line, they often don't have a clue about produce-ability. Why don't those guys get together and let the university be the long-view for industry, and let industry be the produce-ability check for the university? Pooling money/resources–I'll be investing in both, but they should come together to get more out of it.

Oceanography: **Other than investing in both is there a leadership responsibility that you see federal agencies, specifically ONR having in this regard?**

Gaffney: I think ONR is in a better position to take a leadership role in this than other agencies–than the National Science Foundation (NSF). We can be more top-down and they can operate in the reverse-it's a great balance the way we do business and the NSF does business, and we're right next door to each other. We're currently trying to cooperate in engineering areas, like shipbuilding for instance, and in oceanography as well. Maybe there is a chance that an oil exploration company and a university could work together and we could be the funding catalyst for that. I don't think I've seen a proposal in that area, but I like that idea: the dose of reality in the long term, and both groups working together.

Oceanography: **As the Chief of Naval Research and as an ocean scientist and one of the few that have served in both capacities, what are your personal, versus administrative, views of the nature of the international oceanographic community?**

Gaffney: My experience as an oceanographer is as a military specialist in oceanography. I've worked around oceanography in the military context since 1971, and many of my experiences have been international in nature: Vietnam, Indonesia, Spain, and trips to 30-40 other countries. There has been a great interest on the part of the Navy in working with our colleagues around the world for a couple of reasons. One is to reduce the cost of research–whenever you can get a partner, that is good news; getting access to one's waters, gathering data together, perhaps training other nations to increase their skills and then the quid pro quo for that is exchanging data with them, which allows us to get a better picture of the globe. In fact, we are the only global Navy. You can read the front page of the *Washington Post* or the *New York Times* and guess where the Navy might be the very next day based on what is going on. We can go anyplace. And we don't have the wherewithal to characterize the whole ocean ourself. We can do that by cooperating with as many allies as possible and we do that. I've traveled all over the world and have signed agreements with any number of countries: Albania, Russia, Japan, Korea, Indonesia . . . This is critically important for us to do our job. The other part of that is if one wants to cooperate with a neighbor, friend or someone you would like to be your friend, and you're in the military, you would like to be able to develop a trusting relationship, not based on weapons or war fighting. Oceanography is a way for the U.S. Navy to enter–and the Navy is typically the first uniformed service to enter a new country–a new relationship. Oceanography is non-threatening. It is just the opposite. It aids commerce, transportation, and pollution issues. It provides a whole number of things that can help a nation do better. We have great skill in oceanography in the U.S. Navy, or are able to reach it through our principal investigators from ONR because of the data we hold and manage. We have the ability to go in and do very good things with partner nations and be a national spokesman. We are the only agency that really has global kinds of information, global reach, global interests and could actually be the first agency in.

To go back to Albania, before they had their recent troubles just after they became a democracy, the first people into Albania were ocean surveyors. They did a rather unsophisticated kind of oceanography; they went in and mapped their coastline for navigation safety. They collected other data, too. We gave that information to the Albanians and they produced charts. Then all of a sudden commerce started coming in. When we did that, I signed an agreement with the Minister of Defense of Albania, who happened to be a mathematician, and understood immediately what we did, how we did it. He understood global positioning systems and navigation and bathymetry and swath sonars and those types of things and he was incredibly interested in the topic. Now here is a one star admiral working with a Minister of Defense of a very important nation trying to grow into democracy. We signed our agreement, he and I and their Chief of Naval Operations and the whole general staff on national television for just the exchange of a couple of charts–it was just amazing. He said to me that he signed a lot of agreements with new Western Allies, and that this was the first agreement that really delivered something useful for his country.

Oceanography is a way for the U.S. Navy to enter . . . a new relationship.

Oceanography: **Your comments imply an underlying theme of the role of ocean sciences in diplomacy. The State Department has requested the National Academy of Sciences to undertake an assessment of our national investment, if you will, in science and technology as a diplomatic tool. Are we, as a nation, doing everything we can to fully use ocean science and technology as a diplomatic tool?**

Gaffney: I cannot speak for the whole government, because I just don't know what the other agencies are doing proactively in science or oceanography as a tool for better relations between countries. I know that it is important to the U.S. Navy and I know it is very important to ONR. As a mission of ONR, it is one of the reasons we have two foreign field offices: one in Tokyo and one in London, taking care of Asia and Europe. It is a way for us to reach out and peacefully engage our neighbors or people we'd like to have a closer relationship with. It is not threatening and we do it proactively. In both places we have two oceanographers, and they have great connections; that is good news for the U.S.

Navy. I tell senior people in the Navy about this tool that they have. I can apply that to plasma physics and marine corrosion and ship engineering and a whole bunch of other things. I think science is an important way to make connections with people we would like to have a closer relationship with, because it is not provocative and it helps the partner get better as well as us, and it does not cost a lot of money. I guess my opinion is that the nation should use science as a tool to get closer together.

You can look at some of the things Congressman Weldon (R-PA) has done with Russia and the Duma. Whether you agree with it or not, science was a way for him to make good connections. He made excellent connections and opened dialogue that we never even hoped to have. As a matter of fact, it was oceans and environmental sciences that did it. So I think that science should be used in diplomacy as much as possible. It is used actively in the Navy and I would hope that every agency that can use science would.

I think that science should be used in diplomacy as much as possible.

If we do something that is new–a new relationship with a new country, and science or oceanography happens to be a potential lead-in, those activities are always coordinated with the State Department.

Oceanography: **You alluded to the ONR foreign offices, what kinds of services or products would the non-U.S. scientists get from these offices?**

Gaffney: The offices have money to do cooperative research. It is a place where they can go to try to navigate through, at least, the Navy bureaucracy. Remember, the one thing that ONR employees are most proud of is our technical base–we know what is going on. If a French scientist is looking for someone in America or Europe to hook up with, for staff support or collective/collaborative funding for example, a scientific officer might help him with those types of connections. We also sponsor conferences, and workshops that bring people together to exchange ideas. I just did one in Istanbul on electric drives. These opportunities are great for us, but they are also great for our colleagues overseas as well.

I was the CNR for two weeks, and the Prime Minister of Armenia was coming to make his first trip to the United States, and guess where his first stop was, after he got off the airplane?-the ninth floor of ONR. He came in, sat at this table for two hours and talked about a $40,000 investment in research we made in three or four scientists in Armenia that were working on materials for lasers. He said you cannot believe what that investment by the ONR in our country, has done for our prestige and morale. He came here to tell me that personally for two hours.

I will continue to be an advocate of releasing data as long as we do it deliberately . . .

Three of our four Munk Award winners are from outside the U.S.–we fund the best person for the job.

Oceanography: **You cited the relationship with the Russians, which involved the release of data. Recently, the Vice President and others have suggested there will be more declassification of U.S. information, not unlike what was done with the altimetry data. Can you comment on what data might be next?**

Gaffney: There is lots of data that has been released other than the Geosat altimetry . . . most of it is hydrographic station (temperature-salinity with depth) measurements. I would say it is millions of discrete observations that have been released as raw databases. I think the role of the operational oceanographer is great. The role of ONR is to be sure that the operational oceanographers play their role deliberately. You want to make the data available, since it is owned by the taxpayer, but you do not want to make a security mistake. It is a very deliberate process, operational oceanographers consider the value of the data, and determine how to release it so that it retains its scientific value. I would continue to push for a release, because my constituents, the principal investigators supported by ONR, can use that data. The more data they get, the less they have to go out and collect all over again. And we have ways to move data so efficiently, off of home pages, bulletin boards, electronically, at low to no cost to the Navy. I will continue to be an advocate of releasing data as long as we do it deliberately, and we don't make a giant security mistake.

Oceanography: **I'm understanding that the message to the research community is that they can look forward to continued declassification. It's the pace and type of data that are not defined, correct?**

Gaffney: Right, and we are looking at all types of information. If you read the MEDEA report, they would classify that operational data held by the Navy are the crown jewels of oceanography on this planet. That is the data that they are looking at: bathymetry, magnetic, hydrographics, ice data, bioluminescence . . . Getting it out ten years ago would have cost an awful lot of money–it meant standing at the copy machine for ten years and licking stamps all night. Now it is really trivial to get it out. The issue is let's review it, see if it's important, can we release it or can we warp it a little bit so that when we do release it, it doesn't do damage. That is what we are proceeding with and, to my knowledge, the Navy is behind that. I am really behind that because it would help my constituents and it would really save me money.

To really understand the data, you've got to clear somebody–and that matter is not trivial.

Oceanography: **Before we close, what about some general comments on Year of the Ocean?**

Gaffney: The year is not over yet. The President, Vice President, Secretary of Commerce, Secretary of the Navy all showed up at the National Oceans Conference, in addition to a whole lot of good looking and important people. I don't recall, since I started hanging around this political-oceanography business in 1975, a better dialogue or critical mass of folks together. I am very happy that the Secretary of the Navy John Dalton, a former submariner, has become so personally interested in oceanography. He has played a personal role in the Navy's investment in the exposition in Lisbon. He was there for the opening. He was a co-sponsor for the Ocean Conference and participated personally and vigorously and went to tens of briefings on exactly how that conference would be set up and run perfectly. He offered the site for the conference at the Naval Postgraduate School, and he has become a vigorous, comfortable co-chairman of the National Ocean Research Leadership Council of the National Oceanographic Partnership Program. I think that is three times a miracle-and we've had many Secretaries of the Navy that have been interested in oceanography. I can name several of them, but Secretary Dalton has been more interested than any one else. That is just really great news for ONR who has a very large segment of its money invested in oceanography, and the Chief of Naval Research by law reports to the Secretary of the Navy. To have your boss intimately interested in the largest chunk of your investment is great. So, to me, the Year of the Ocean was a magnificent success.

We are a maritime nation and I think it is insane for the United States not to understand why the ocean is a part of why we are a great nation– it acts as both an insulator, and a conductor of this country.

We are a maritime nation and I think it is insane for the United States not to understand why the ocean is a part of why we are a great nation–it acts as both an insulator, and a conductor of this country. It keeps the bad things away, but it also brings us to the rest of the world. To not understand that medium is insane.

The Navy needs to understand maritime weather on the oceans, and that's what makes the Navy and the Marine Corps different from the other services. The Year of the Oceans put a spotlight on that. When the Secretary of the Navy gets involved in the Year of the Oceans, 45 admirals get involved as well, whether they like it or not, and now they all know about it.

Oceanography: **Finally, consider the TOS international audience and a young graduate in ocean scientist coming into the research community right now. What is your advice?**

Gaffney: What is your goal in life? Do you want to make a difference, live in a nice place, have adventure, or make a lot of money? Some of those things apply to research oceanographers, some don't. You're probably not going to be real rich. You'll probably be away from home a lot. On the other hand, you'll definitely have more adventures than your buddy down the street will.

And you've got to want to do something that is very important-I think the world is figuring out that the ocean is very important. We see threats to the environment. There's an awful lot of speculation whether there is global change going on and we have the chance to determine whether or not that is happening, and do something about it. The next generation is going to do something about that–the old guys are not going to do anything about that. The people in school, the post-docs now are going to have to wrestle with that problem and it could be a major issue. Just think of this. About 50%-maybe 75% of the world's population lives within 200km of the ocean, attracted by good recreation, better weather, and transportation options. Before the people you're talking about die, the population of the earth–at the rate we're going now-will double. I predict the same ratio will live along the shores–the stresses that will put on the edge of the ocean are incredible.

So I believe there is an incredible amount of work out there. Will you get rich? No. Will you do important, maybe the most important things for the planet? Yes, I think so. Will it be adventurous? Yes, absolutely. I would encourage you to go into the field, but if you go in thinking you're going to make a lot of money, be a millionaire being an ocean researcher, don't.

Small-Scale Hydrodynamics of Feeding Appendages of Marine Animals

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Many animals in the ocean use appendages bearing arrays of hairs to capture molecules from the surrounding fluid (e.g. feathery gills take up oxygen; olfatory antennae capture odorants), to capture food particles (e.g. hairy suspension-feeding appendages catch single-celled algae), or to move the fluid around them (e.g. setulose appendages are used to swim or create ventilatory currents). Since hairy little appendages serve such important biological functions in animals from so many phyla, we have been trying to elucidate the basic rules governing how they all work.

Hydrodynamics of "Hairy Little Legs"

The performance of all the functions mentioned above (e.g. capturing molecules or particles; moving water) depends on how the arrays of hairs interact with the water around them (e.g. Koehl, 1981; 1995; Childress, et al., 1987). Therefore, the first step in analyzing how hairy appendages work is to figure out how fluid moves around and through them. The Reynolds number (Re) of a structure moving through a fluid represents the relative importance of inertial to viscous forces determining how the fluid moves; $Re = \rho LU/\mu$, where L is a linear dimension of the structure, U is fluid velocity relative to it, and ρ and μ are the density and viscosity (resistance to being sheared) of the fluid (e.g. Vogel, 1994). At high Re (e.g. large, rapidly-moving structures), inertial forces predominate and flow is messy and turbulent, whereas at low Re (e.g. small, slowly-moving structures), viscosity damps out disturbances in the fluid and flow is smooth and orderly. When fluid flows past a solid surface, the fluid in contact with the surface does not slip relative to the surface and a velocity gradient develops between the surface and the freestream flow. At low Re, this layer of sheared fluid between the surface of a moving structure and the still surrounding fluid is thick relative to the dimensions of the structure (e.g. Koehl, 1981; 1995). If we calculate the Re at which the hairs on the types of appendages listed above operate (using hair diameter for L), we find that they range between 10^{-5} and 10 (Rubenstein & Koehl, 1977; Koehl and Strickler, 1981; Cheer and Koehl, 1987; 1988; Loudon, *et al.*, 1994; Koehl, 1995). In this Re range viscosity is very important in determining flow patterns (although we cannot ignore the effects of inertia at the upper end of this Re range, Cheer and Koehl, 1987; 1988; Koehl, 1992; 1995). Since humans operate at high Re (approximately 10^6 when swimming), we cannot trust our intuitions when considering the viscous flow around arrays of little hairs.

. . . the first step in analyzing how hairy appendages work is to figure out how fluid moves around and through them.

In order to understand how arrays of hairs capture molecules or particles, or push fluids around, the first thing that we need to figure out is whether fluid flows through the gaps between the hairs in an array, or flows around the sides of the array rather than through it. We have defined the "leakiness" of an array of hairs as the proportion of the water encountering the gap between adjacent hairs that actually flows through the gap (Cheer and Koehl, 1987). The leakiness of a hair-bearing structure determines whether or not the structure can function as a filter, and it also affects the flux of molecules to hair surfaces and the ability of the appendage to generate thrust or lift (e.g. Koehl, 1995; 1996a). Since there is diversity in the the size, structure, and behavior of hair-bearing appendages, another important piece of the puzzle that we have to address is how the morphology and motion of a hairy leg affect its leakiness (Koehl, 1983; 1995; 1996b; Loudon, *et al.*, 1994).

A general model of flow between neighboring hairs permits us to examine how the size, spacing, and speed of an array of hairs affect its leakiness (Cheer and Koehl, 1987; 1988). At small hair sizes ($Re = 10^{-5}$ to 10^{-3}), arrays of hairs have very low leakiness (i.e. only a small proportion of the water or air encountered actually goes through the gaps between hairs, while most flows around the array) and function like non-porous paddles. In contrast, from Re of 10^{-2} to 1, a transition in leakiness occurs: a structure that functioned like a paddle at low speed and small size becomes a leaky sieve at faster speed or larger size. We can apply these general principles to study how "hairy little legs" (such as the feeding appendages of copepods) work, and how their structure and behavior affect their performance.

Copepod Feeding Appendages

Calanoid copepods are abundant planktonic crustaceans that play a critical link in many marine food webs between single-celled algae and higher trophic levels such as fish. Since copepod feeding is so ecologically important, many studies measuring copepod feeding rates and selectivity have been conducted (reviewed in Koehl, 1984). To complement these studies, we have been working to figure out the physical mechanisms copepods use to catch particles like single-celled algae. High-speed microcinematography of seawater labeled with dye and released from miciopipettes near the animals while they were catching food particles revealed the appendage and water motions involved in copepod feeding (Koehl and Strickler, 1981; Koehl and Paffenhöfer, unpubl. data). The last stage in particle capture is performed by a pair of setulose appendages, the second maxillae (M2's; Fig. 1), that fling apart from each other and then squeeze back together again. Some species perform this capture motion with their setae (hairs) operating at Re of order 1, whereas others do it at hair Re as low as 10^{-2} (Koehl, 1981; Koehl and Strickler, 1981; Koehl, 1992; 1995). Remember, this represents the critical Re range in which the transition occurs between non-leaky paddle-like behavior and leaky sieve-like function.

. . . even though their feeding motions look qualitatively similar, the physical mechanisms by which these two copepods capture food are different . . .

Analysis of the motions of M2's, particles, and dye in the movies of feeding copepods revealed that species such as *Centropages velificatus* that have coarsely-meshed M2's (Fig. 1) whose setae (hairs) operate at Re = 1, have leaky M2's and filter their food from the water during the squeeze (Koehl, 1995). In contrast, other species such as Temora stylifera that have finely-meshed (Fig. 1), slowly-moving M2's whose setae operate at Re = 10^{-2}, have paddle-like M2's that capture food by drawing a parcel of water containing an alga towards the mouth during the fling (Koehl 1981; Koehl and Strickler, 1981; Koehl, 1995). Thus, even though their M2 feeding motions look qualitatively similar, the physical mechanisms by which these two copepods capture food are different because they operate at Re above and below the transition from paddle to sieve. These copepod M2's provide examples of hairy appendages that look similar to each other and that move qualitatively in the same way, but that capture algal cells by different mechanisms during that motion simply because they operate at Reynolds numbers on either side of the transition in leakiness.

We have been using physical models of copepod M2's to tease out whether leakiness is affected by the coarseness of the mesh of hairs on the M2's as well as by their speed. Like mathematical models, physical models permit us to vary only one parameter at a time to quantify its effects while holding all the other vari-

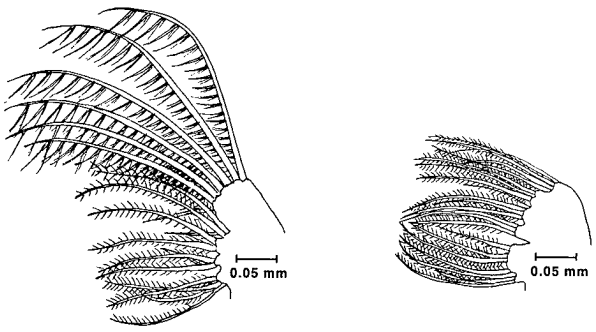

Figure 1. Diagrams of second maxillae from the calanoid copepods Centropages velificatus (whose setae operate at Reynolds numbers of order 1) and of Temora stylifera (whose setae operate at Reynolds numbers of order 10^{-2}).

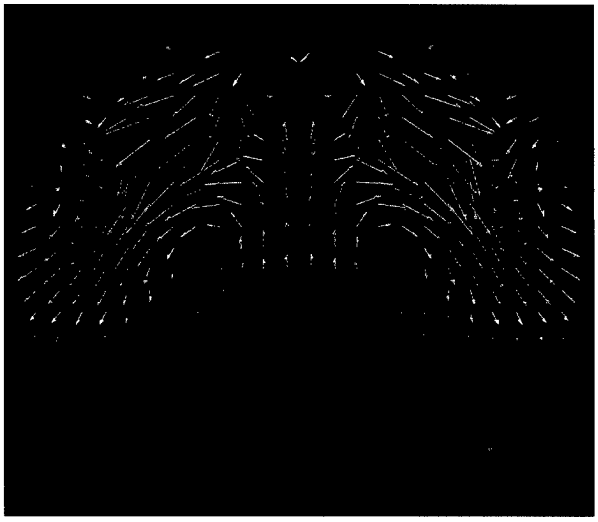

Figure 2. Diagram of the net displacement of water produced by the "fling-and-squeeze" motion of a pair of food-particle-capturing appendages (second maxillae, M2's) of the calanoid copepod Centropages velificatus (arrows indicate water direction and their color represents distance moved: blue ~ 460μm, green ~ 230μm, red < 1mm). The gray bars indicate the positions of the M2's (390μm long) after the fling-and-squeeze is completed, and the gray circles represent the hinges between the M2's and the body surface of the animal. We are looking down on the anterior end of a copepod that is vertical in the water; the body of the animal is at the top of the picture, the M2's are on the ventral surface, and the mouth is midway between the M2's. During the fling, the M2's rotate away from each other, and during the squeeze, they rotate back towards each other. Some copepods operate their M2's so slowly that little water flows through the array of setae (hairs) on an M2, which therefore functions like a paddle moving water containing food particles towards the mouth. In contrast, C. velificatus moves its M2's more rapidly and water flows through rather than around the array of hairs on each M2. These leaky M2's can filter particles from the water moving through them, whereas paddle-like M2's cannot. As this diagram indicates, water is drawn towards the mouth and is passed laterally through the M2's when a C. velifacatus does a fling-and-squeeze. This flow visualization was made using a dynamically-scaled physical model of a pair of C. velificatus M2's attached to a body surface, and this image was produced by T. Cooper using the particle image velocimetry program described by Cowan and Monismith (1997).

ables constant (Koehl, 1992; 1995); such manipulations are not possible in comparative studies with real animals. If a physical model and the propotype M2's are geometrically similar and operate at the same Re, then the ratios of the velocities and the forces at comparable positions in the flow field around the model are the same as those around the M2 (Vogel, 1994). Therefore, we can slowly flap large models of copepod M2's in high viscosity mineral oil at the Re used by the copepods, and we can also change the speeds of the models to make them operate at different Re used by other

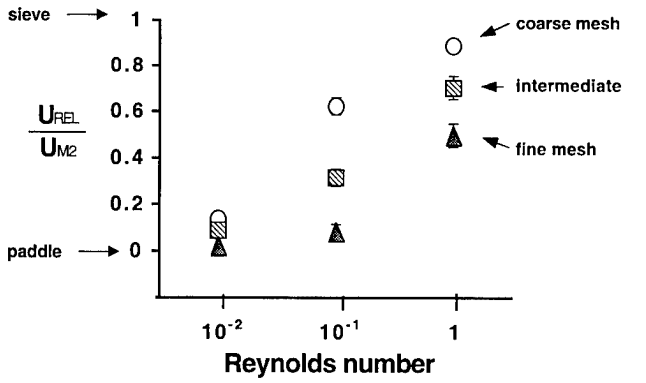

Figure 3. Flow through the middle of the array of hairs on models of the second maxillae of calanoid copepods: Centropages velificatus (coarse mesh of hairs on the second maxillae; indicated by circles), Eucalanus pileatus (intermediate mesh; shown by squares), and Temora stylifera (fine mesh; indicated by triangles). U_{REL} is the velocity of fluid between the hairs relative to the hairs, and U_{M2} is the speed of the second maxilla; the ratio U_{REL}/U_{M2} is an indication of leakiness (values near one are leaky and sieve-like, while values near zero are un-leaky and paddle-like). Even though C. velificatus operate their second maxillae at seta Reynolds numbers of order 1, while the other two species operate at Re of order 10^{-2}, we could run the models at any Re we chose. These experiments showed that at a Reynolds number of 10^{-2}, the coarseness of the mesh of hairs on a second maxilla makes no difference to its leakiness, whereas at Reynolds numbers of 10^{-1} and 1, coarsely-meshed appendages are leakier than finely-meshed ones (error bars indicate one standard deviation, n = 3 to 12).

species. By videotaping the paths of neutrally-buoyant marker particles in the fluid, we have measured the flow produced during the fling and squeeze (Fig. 2) and we have used these data to calculate the M2 leakiness. From such experiments we learned that the coarser the mesh, the leakier the M2's at Re $\geq 10^{-1}$, but that at Re = 10^{-2}, mesh coarseness has no effect on leakiness (Fig. 3). Although this result—that the morphology of an appendage only affects its performance at some Re, but not at others–seems non-intuitive, it was predicted from the basic physics of how fluids flow around cylinders (Cheer and Koehl, 1987; 1988; Koehl, 1992; 1995). We are now applying the same principles to investigate molecule capture by "hairy little noses" (e.g. we are studying the hydrodynamic design of olfactory antennules of a variety of crustaceans) (Koehl, 1996b).

REFERENCES

Cheer, A. Y. L. and M. A. R. Koehl, 1987: Paddles and rakes: Fluid flow through bristle appendages of small organisms. *J. Theor. Biol.*, 129, 17-39.

Cheer, A. Y. L. and M. A. R. Koehl, 1988: Fluid flow through filtering appendages of insects. *I.M.A. J. Math. Appl. Med. Biol., 4,* 185-199.

Childress, S., M. A. R. Koehl, and M. Miksis, 1987: Scanning currents in Stokes flow and the efficient feeding of small organisms. *J. Fluid Mech., 177,* 407-436.

Cowen, E.A., and S.G. Monismith, 1997: A hybrid digital particle tracking velocimetry technique. *Experiments in Fluids, 22,* 199-211.

Koehl, M. A. R., 1981: Feeding at low Reynolds number by copepods. *Lectures in Mathematics in the Life Sciences, 14,* 89-117.

Koehl, M. A. R., 1983: The morphology and performance of suspension-feeding appendages. *J. Theor. Biol., 105,* 1-11.

Koehl, M. A. R., 1984: Mechanisms of particle capture by copepods at low Reynolds number: Possible modes of selective feeding. In: *Trophic Interactions Within Aquatic Ecosystems.* D. L. Meyers and J. R. Strickler, eds., Westview Press, 135-160.

Koehl, M. A. R., 1992: Hairy little legs: Feeding, smelling, and swimming at low Reynolds number. Fluid Dynamics in Biology. *Contemporary Mathematics, 141,* 33-64.

Koehl, M. A. R., 1995: Fluid flow through hair-bearing appendages: Feeding, smelling, and swimming at low and intermediate Reynolds number. *Soc. Exp. Biol. Symp., 49,* 157-182.

Koehl, M. A. R., 1996a: When does morphology matter? *Ann. Rev. Ecol. Syst., 27,* 501-542.

Koehl, M. A. R., 1996b: Small-Scale fluid dynamics of olfactory antennae. *Mar. Fresh. Behav. Physiol., 27,* 127-141.

Koehl, M. A. R. and J. R. Strickler, 1981: Copepod feeding currents: Food capture at low Reynolds number. *Limnol. Oceanogr., 26,* 1061-1073.

Loudon, C., B. A. Best, and M. A. R. Koehl, 1994: When does motion relative to neighboring surfaces alter the flow through an array of hairs? *J. Exp. Biol., 193,* 233-254.

Rubenstein, D. I. and M. A. R. Koehl, 1977: The mechanisms of filter feeding: Some theoretical considerations. *Amer. Natur., 111,* 981-994.

Vogel, S., 1994: *Life in Moving Fluids: The Physical Biology of Flow, 2nd Edition.* Princeton University Press, Princeton.

Controls on Floc Size in the Sea

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Introduction

If you scoop a glass of water from the sea and look beyond the wonders of biology therein, you see particles (Fig.1). Detritus of the many biogeochemical processes at work in the ocean, particles influence fundamentally the transport of mass and transmission of energy through the water column. Particle sinking is a major pathway for transfer of carbon and nutrients from surface waters to the deep sea, thereby playing a crucial role in global climate (Suess, 1980; Asper et al., 1992). Particles offer abundant surface area for adsorption of numerous hydrophobic anthropogenic contaminants, so the fate of pollutants in the sea is linked inextricably with the fate of particles (Milligan and Loring, 1997; Gustafsson et al., 1998). Particles scatter light, so they affect the growing conditions for phytoplankton at the base of the oceans' food webs (Campbell and Spinrad, 1987; Bricaud et al., 1995). Concealed within particles that come to rest on the seafloor is a record of environmental change that paleoceanographers and geologists are devoting great effort to unraveling (Kranck, 1984; McCave et al., 1995). The list of particle roles in the sea goes on, but perhaps this one is sufficient to make the point that understanding of particles is a keystone for overall understanding of the seas.

Figure 1 A photograph of particles in suspension 130 m below the surface of Disenchantment Bay, a fjord in Southeast Alaska. The bright line at the right is the light source. For scale, the centers of the two calibration objects in the middle of the image are 5 cm apart. The white specs are flocs that are approximately 1 mm in diameter and account for about 3/4 of the mass in suspension.

. . . understanding of particles is a keystone for overall understanding of the seas.

The myriad roles played by particles in the sea all are affected by particle size distribution. One of the great gifts of nature to curious scientists is the fact that surface-area-to-volume ratio decreases with increasing particle size. This simple fact makes large particles sink faster than smaller ones of the same composition; it makes small particles more adsorptive per unit of mass; and it makes larger particles scatter less light per unit of mass than smaller particles. The fundamental importance of particle size distribution has bred continuing efforts to quantify it in the sea.

One of the most important lessons learned from studies of marine particle size distributions is that often the majority of particles in the sea do not exist as single grains, but rather are parts of large aggregates of particles, variously called flocs, aggregates, or, more poetically, marine snow (Eisma, 1986; Fowler and Knauer, 1986). Instruments that estimate particle size without collecting or otherwise disturbing a suspension show that mass typically resides in a relatively uniform population of flocs with diameters of several hundred micrometers or more (Figs. 1 and 2). If that same suspension is collected and purposely reduced to its component particles, a poorly sorted population of particles orders of magnitude smaller than the parent flocs emerges (Kranck and Milligan, 1992). By using estimated size-density relationships for flocs, the mass concentration in flocs can be estimated, and it often accounts for well over half of the total mass in a suspension. Thus, developing knowledge of floc properties lies on the road to understanding marine particle dynamics.

The tendency of particles to flocculate complicates considerably the task of developing predictive knowledge of particle dynamics. In the simplest models that incorporate flocculation, particles can exist as single grains or flocs (Kranck and Milligan, 1991; Lavelle, 1993). Predicting their fate requires expressions for single-grain and floc settling velocities, as well as terms for exchange rates, via aggregation and disaggregation, between single grain and floc populations. Settling velocities of single grains are well understood, but settling velocities of flocs, aggregation rate, and disaggregation rate are not. Therefore, these three topics have garnered much attention in recent research into marine particle dynamics.

Three hypotheses regarding floc settling velocity and breakup make implementation of even simple models daunting (Dyer, 1989). First, floc settling velocity pre-

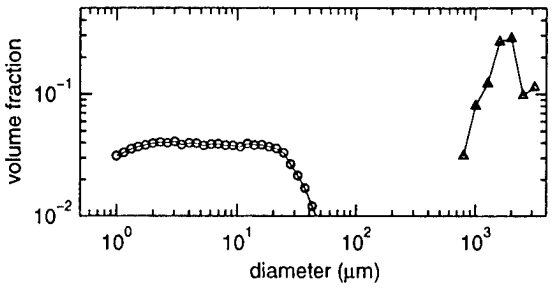

Figure 2 In situ floc size distribution (triangles) and disaggregated inorganic size distribution (circles) from the image in Fig. 1. The floc size distribution derives from image analysis of the digitized photograph, and the disaggregated size distribution was generated using a Coulter Multisizer IIe to analyze the contents of a Niskin bottle collected at the same depth as the photograph. Although no organic particles are represented in the disaggregated size distribution, the environment at the head of the fjord where these samples were taken was dominated by inorganic silt and clay discharged at the tidewater terminus of Hubbard glacier. Component inorganic grains are poorly sorted and orders of magnitude smaller than the well-sorted flocs in which they are packaged in situ.

sumably depends on suspended particle concentration. Second, floc settling velocity is limited by turbulence-induced forces, and third, physical disaggregation by turbulence is the dominant mechanism for liberating mass from flocs. If all of these hypotheses are true, a predictive understanding of particle dynamics requires detailed knowledge of the spatial and temporal distribution of particle concentration and turbulence in a suspension. The goal of this paper is to provoke discussion by outlining the conceptual basis for these hypotheses; evaluating data used to support them; and discussing recent observations that cast doubt on their validity. These observations are particularly exciting because they suggest that under a wide range of conditions, a much simpler model of floc dynamics may suffice.

Alternative hypotheses that can explain direct floc observations as well as settling-column data are needed.

Floc Settling Velocity and Concentration

A common assumption in fine-sediment research holds that floc settling velocity increases as sediment concentration grows (Dyer, 1989). A compelling argument underlies this assumption. It maintains that maximal floc size and settling velocity reflect a dynamical balance between aggregation and disaggregation rates. Aggregation rate, which scales with the square of concentration, increases faster with increasing concentration than does disaggregation rate, which only scales linearly with concentration. As a result, increases in concentration push the size for which aggregation and disaggregation rates balance to larger diameters.

Data from field-deployed settling columns have long been used to support the assumption that floc settling velocity depends on concentration (Burt, 1986; Dyer et al., 1996) (Fig. 3). In general, these devices operate by enclosing a volume of suspension that is monitored to determine clearance rate of sediment mass. Several techniques have been used to convert clearance rate to a median effective settling velocity, $w50$, for the suspension. These settling columns consistently produce values of $w50$ that increase with increasing concentration (Fig.3).

Studies using direct observations of flocs to test explicitly the hypothesis that floc size and settling velocity depend on concentration have failed to find evidence supporting it. ten Brinke (1994) made direct videographic observations of floc settling velocity in the field, and he found no dependence on concentration. Milligan and Hill (1998) photographically examined maximal floc size as a function of concentration in a laboratory flocculator and also saw no relation (Fig.4). The failure of direct observations to support this hypothesis seriously compromises it. The settling-column data invoked to support it are indirect and open to other interpretations. Alternative hypotheses that can explain direct floc observations as well as settling-column data are needed.

Floc Settling Velocity and Turbulence

Another common assumption in fine sediment research is that under all conditions maximal floc settling velocity is controlled by turbulence (Jackson, 1995; Hill, 1996; Ruiz and Izquierdo, 1997). This assumption rests on the third common assumption in floc studies, which states that turbulence-induced stresses dominate particle disaggregation. These assumptions derive from many observations of reductions in floc size associated with vigorous turbulence (Kranck and Milligan, 1992; Luettich et al., 1993; Eisma et al., 1996).

No explicit tests of the hypothesis that floc settling velocity depends on turbulence have been conducted in the laboratory or the field. Yet numerous in situ direct observations of sinking flocs from diverse environments yield similar results, casting doubt on the notion that

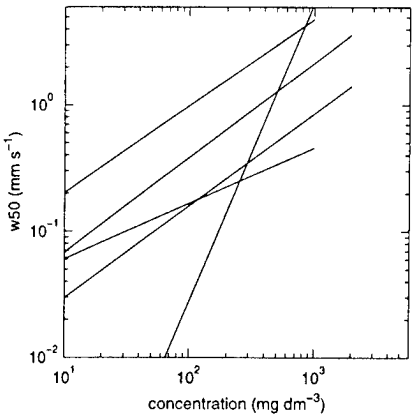

Figure 3 Best fits of median effective settling velocity (w50) to concentration from Dyer et al. (1996). In an inter-comparison of instruments for measuring settling velocity, various in situ settling columns all produced increases in clearance rate with increasing concentration. These results were interpreted as indicative of concentration dependence of floc settling velocity. An alternative explanation is that concentration dependence of clearance rate reflects the action of floc breakup and reformation in the columns. See text for details.

Table 1: Settling velocities from direct observations		
Settling velocity mm s^{-1}	Environment	Source
1.3	upwelling region	Alldredge and Gotschalk (1989)
0.56-2.82	estuary	van Leussen and Cornelisse (1993)
1.54	estuary	ten Brinke (1994)
1-3	estuary	Dyer et al. (1996)
2.2	fjord	Hill et al. (1998)
1-3.8	continental shelf	Sternberg et al. (in press)

turbulence plays a key role in determining settling velocity. Such observations were made in 1995 by deploying an in situ camera in Tarr Inlet, Glacier Bay, Alaska (Hill et al., 1998). The camera took series of photographs in which flocs were sized and tracked from image to image. From size and settling velocity, effective density was calculated. The data gathered in Tarr Inlet bear close resemblance to data gathered elsewhere with different instruments. First, floc effective density decreases with increasing floc size (Fennessy et al., 1994; ten Brinke, 1994, Syvitski et al., 1995; Dyer et al., 1996) (Fig. 5). This behavior stems from incorporation of progressively more pore space into flocs as they grow. The correlation of porosity and size leads to dependence of settling velocity on diameter that is weaker than the dependence predicted by Stokes Law for particles of constant density. Second, and more importantly, the mean floc settling velocity in Tarr Inlet is approximately 2 mm s^{-1}, which is close to settling velocity estimated by direct observations in a variety of other environments (Table 1).

Indirect methods of estimating in situ settling velocity also yield values in the range of a mm s^{-1}, or in perhaps more familiar units, 100 m day^{-1}, (Table 2). Sediment traps deployed around the globe in a variety of environments reveal lags between sedimentation events at different depths that are best explained by repackaging of particles into flocs sinking at 100 m day^{-1}. Simulations of vertical distribution of fine suspended sediment in bottom boundary layers often require settling velocities in the range of 1 mm s^{-1} in order to fit data.

Although estimates of turbulent energy do not accompany the numerous observations and extrapolations of floc settling velocities of order 1 mm s^{-1}, the energy levels in the variety of environments from which the values come clearly differ. Environments range from quiescent ocean interior to a continental shelf stirred by waves and tides to the macrotidal Bay of Fundy (Tables 1 and 2). If turbulence controls floc settling velocity in these diverse settings, measured fall rates should differ. The fact that they do not warrants a search for alternative explanations.

Disaggregation and Turbulence

The assumption that turbulence destroys flocs underlies most studies of marine particle dynamics (Jackson, 1995; Hill, 1996; Ruiz and Izquierdo, 1997). Floc diameters generally fall below the dimension of the smallest eddies in a turbulent suspension. At these small scales, turbulence induces linear shear that presumably rends flocs. The magnitude of the shear is determined by the turbulent-kinetic-energy dissipation rate, ε. Numerous theoretical studies in the fields of material processing and wastewater treatment have investigated turbulence-mediated breakup of flocs. In general such theories predict that maximal floc size scales as ε^{-b} where the exponent b varies between $^1/_4$ and 1, depending on breakup mechanism (Burt, 1986; Alldredge et al., 1990). Laboratory studies generally support these theories, so oceanographers have applied similar models of disaggregation to marine particles.

Ample evidence exists suggesting that turbulence can destroy flocs. Observations of flocs in the field show that smaller flocs occur in higher energy environments (Kranck and Milligan, 1992; Luettich et al., 1993; Berhane et al., 1997). Vertical profiles of floc size in an estuary show that smaller flocs occur near the seabed, where turbulent-kinetic-energy dissipation rates are higher (Eisma et al., 1996), and laboratory studies also show that floc size decreases as ε increases (Milligan and Hill, 1998). Recent observations, however, challenge the idea that turbulence *dominates* floc breakup in the sea.

Although it is clear that turbulence can disrupt flocs, the turbulent-kinetic-energy dissipation rates required to do so apparently exceed those found throughout much of the ocean.

Although it is clear that turbulence can disrupt flocs, the turbulent-kinetic-energy dissipation rates required to do so apparently exceed those found throughout much of the ocean. In a laboratory study, Alldredge et al. (1990) introduced five different types of flocs into an oscillating grid turbulence tank. Maximal ε in the tank was greater than 10^{-4} W kg^{-1}, which is large relative to typical ε in the ocean (Alldredge et al., 1990). It was surprising, therefore, that 3 of 5 floc types experienced no disruption in the tank. Only fragile diatom flocs suffered any breakage, and many of these remained intact. Recent in situ observations of floc size and turbulent shear in a continental-shelf bottom boundary layer support the finding that floc breakage occurs only at relatively high turbulence intensity (Hill et al., submitted).

Table 2: Inferred settling velocities		
Settling velocity mm s^{-1}	Environment	Source
> 0.7	upwelling region	Honjo (1982)
1.2-1.7	open ocean	Billet et al. (1983)
2.1	macrotidal estuary	Amos and Mosher (1985)
≈ 1.2	open ocean	Deuser (1986)
> 1.2	open ocean	Asper et al. (1992

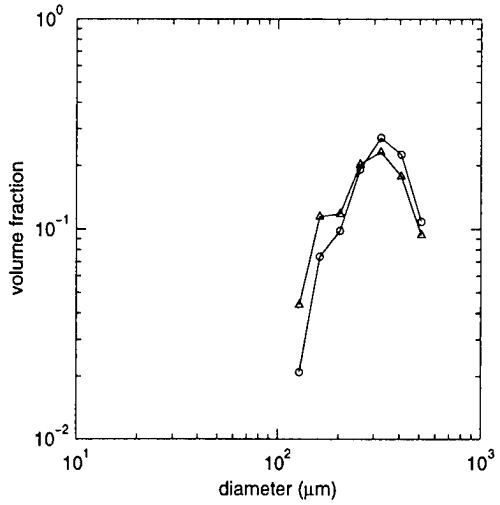

Figure 4 In situ floc size distributions at two concentrations in a laboratory flocculator. The size distribution of flocs of glacimarine clay at a concentration 50 mg dm^{-3} (circles) does not differ significantly from the size distribution at 250 mg dm^{-3} (triangles). These observations, redrawn from Milligan and Hill (1998), support other data that show that floc size and settling velocity do not depend on sediment concentration.

Adding to doubt concerning the central role of turbulence in destroying flocs are observations that indicate that the dependence of maximal floc size on ε generally is not as strong as predicted. Three floc types in the Alldredge study showed no dependence on ε over the large range in the tank. For another floc type in the Alldredge study, maximal floc size scaled as $\varepsilon^{-0.11}$, whereas the weakest predicted dependence goes as $\varepsilon^{-0.25}$. Only one floc type yielded a power-law dependence of maximal floc size on ε that was not significantly different from theory. Recent in situ observations similarly show much-weaker-than-predicted dependence of maximal floc size on parameters related to ε (Hill et al., submitted). These disagreements between theory and observations once again suggest our current understanding of floc dynamics needs refinement.

. . . direct observations argue for a simpler view of flocs . . .

Alternative Hypotheses

Three hypotheses that are central to understanding floc dynamics fail to explain observations. Alternative hypotheses have been developed that do accommodate recent data. The new view of floc dynamics embodied by these alternatives is considerably simpler than the conventional view.

The first set of observations that clashes with conventional wisdom is the lack of correlation between floc settling velocity and concentration. An alternative explanation for the observed dependence of clearance rate on concentration in settling columns is that floc breakup and reformation produce observed results (Milligan, 1995; Milligan and Hill, 1998). According to this hypothesis, intense turbulence caused by sampling destroys larger flocs. Once enclosed in a relatively quiescent column, floc fragments recombine into large flocs and sink out at a floc settling velocity that does not depend on concentration. The time required to complete this two-step removal pathway decreases as concentration grows because the time required for formation of flocs scales inversely with concentration (Gonzalez and Hill, in press), not because of any concentration dependence of floc settling velocity. Thus, supposed concentration-dependence of settling velocity is a methodological artefact, and knowledge of concentration is not necessary to model floc sinking.

The relative uniformity of floc settling velocity, the observation that flocs tend to break only at high values of ε, and the weaker-than-predicted dependence of maximal floc size on ε all challenge the view that turbulence limits floc size and settling velocity under all conditions is the sea. Alldredge et al. (1990) proposed microbial degradation, bacterial solubilization, and animal grazing as other mechanisms for limiting floc size in the sea. It is difficult, however, to reconcile these mechanisms with the observed uniformity of floc settling velocities. Settling velocities of order 1 mm s^{-1} have been observed for diverse floc types ranging from diatom-rich marine snow to predominantly inorganic mineral flocs (Alldredge and Gorschalk, 1989; Hill et al., 1998) (Tables 1 and 2). The chemical and biological processes going on within these flocs likely differ and would not be expected to limit flocs to the same general settling velocity.

An alternative hypothesis for control of floc size is that forces imposed on flocs during sinking limit their size (Hill et al., 1998). Sinking obviously induces relative particle-fluid motion, and such motion exerts stresses on a particle. Although sinking-induced stresses are not large, scale analysis shows that at the relatively low values of ε in the ocean, they often exceed turbulence-induced stresses.

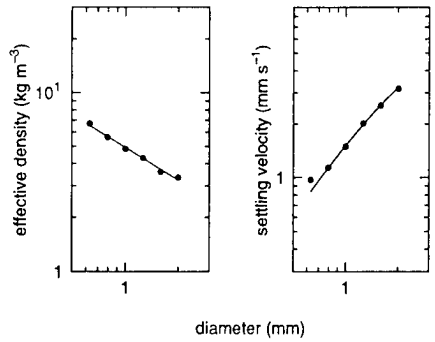

Figure 5 In situ, bin-averaged floc effective density and settling velocity near the seabed of Tarr Inlet, Glacier Bay, Alaska, redrawn from Hill et al. (1998). Floc effective density decreases as diameter raised to the power -0.61, so settling velocity increases approximately as diameter raised to the 1.39. These relationships arise because flocs incorporate progressively more pore space into their structure as they grow. Mean floc settling velocity for these data is about 2 mm s^{-1}, a number consistent with floc settling velocities observed in a variety of environments (Tables 1 and 2). The uniformity of floc settling velocities across environments suggests that, under a wide range of energy, turbulence likely does not limit floc settling velocity.

The control of floc size by sinking- and turbulence-induced stresses has received rigorous theoretical treatment by P. M. Adler. His models (Adler and Mills, 1979; Adler, 1979) produced two particularly interesting results. First, he found that below some critical shear, whose value depended on particle strength, shear ceased to limit aggregate size. Second, he determined that stresses induced by sinking always limit floc size. Thus, according to Adler's models, below some critical value, floc size ceases to vary with shear. Above that value, floc size decreases as shear grows. These predictions are more consistent with observations than are the predictions of models that assume that turbulence alone limits floc size. Under this paradigm, modelling particle dynamics becomes much easier under a wide range of conditions. As long as ε falls below some critical, apparently high, value, floc size and settling velocity do not depend on temporally and spatially varying turbulence levels.

Conclusions

The advent of technologies for observing flocs directly has shaken the foundations of understanding of floc dynamics in the sea. Indirect observations from settling columns and theory and observations refined for vigorously agitated suspensions support the long-held ideas that factors external to flocs, namely sediment concentration and turbulence, exert strong control over floc properties. At this time, direct observations argue for a simpler view of flocs, specifically that over a wide range of concentration and turbulence intensities, external factors do not influence floc properties. As more and better in situ observations become available, it will become clear under what conditions the simpler view should prevail.

Acknowledgments: I wish to thank Tim Milligan for the almost daily conversations we have on topics like the ones in this paper. I am grateful to Joe Kravitz and James Syvitski for encouraging and supporting extension of my research to the field. This work was funded primarily by the U. S. Office of Naval Research Coastal Mixing and Optics Program.

References

Adler, P. M., 1979: A study of disaggregation effects in sedimentation. *AIChE Journal, 25(3),* 487-493.

Adler, P.M. and P.M. Mills, 1979: Motion and rupture of a porous sphere in a linear flow field. *Journal of Rheology, 23(1),* 25-37.

Alldredge, A.L. and C.C. Gotschalk, 1989: Direct observations of the mass flocculation of diatom blooms: characteristics, settling velocities and formation of diatom aggregates. *Deep-Sea Research, 36(2),* 159-171.

Alldredge, A.L., T.C. Granata, C.G. Gotschalk, and T.D. Dickey, 1990: The physical strength of marine snow and its implications for particle disaggregation in the ocean. *Limnology and Oceanography, 35(7),* 1415-1428.

Amos, C.L. and D.C. Mosher, 1985: Erosion and deposition of fine-grained sediments from the Bay of Fundy. *Sedimentology, 32,* 815-832.

Asper, V.L., W.G. Deuser, G.A. Knauer and S.E. Lohrenz, 1992: Rapid coupling of sinking particle fluxes between surface and deep ocean waters. *Nature, 357,* 670-672.

Berhane, I., R.W. Sternberg, G.C. Kineke, T.G. Milligan and K. Kranck, 1997: The variability of suspended aggregates on the Amazon continental shelf. *Continental Shelf Research, 17(3),* 267-286.

Billet, D.S.M., R.S. Lampitt, A.L. Rice, R.F.C. Mantoura, 1993: Seasonal sedimentation of phytoplankton to the deep-sea benthos. *Nature, 302,* 520-522.

Bricaud, A., C.R. Roesler, and J.R.V. Zaneveld, 1995: In situ methods for measuring the inherent optical properties of ocean waters. *Limnology and Oceanography, 40(2),* 393-410.

Burt, T.N., 1986: Field settling velocities of estuary muds. In *Estuarine Cohesive Sediment Dynamics,* A.J. Mehta. ed. Springer-Verlag, 126-150.

Campell, D.E. and R.W. Spinrad, 1987: The relationship between light attenuation and particle characteristics in a turbid estuary. *Estuarine Coastal and Shelf Science, 25,* 53-65.

Deuser, W.G., 1986: Seasonal and interannual variations in deep-water particle fluxes in the Sargasso Sea and their relation to surface hydrography. *Deep-Sea Research, 33(2),* 225-246.

Dyer, K.R., 1989: Sediment processes in estuaries: future research requirements. *Journal of Geophysical Research, 94(C10),* 14,327-14,399.

Dyer, K.R., J. Cornelisse, M.P. Dearnaley, M.J. Fennessy, S.E. Jones, J. Kappenberg, I.N. McCave, M. Pejrup, W. Puls, W. Van Leussen, and K. Wolfstein, 1996: A comparison of in situ techniques for estuarine floc settling velocity measurements. *Journal of Sea Research, 36-(1-2),* 15-29.

Eisma, D., 1986: Flocculation and de-flocculation of suspended matter in estuaries. *Netherlands Journal of Sea Research, 20(2/3),* 183-199.

Eisma, D., A.J. Bale, M.P. Dearnaley, M.J. Fennessy, W. Van Leussen, M.A. Maldiney, A. Pfeiffer and J.T. Wells, 1996: Intercomparison of in situ suspended matter (floc) size measurements. *Journal of Sea Research, 36(1-2),* 3-14.

Fennessy, M.J., K.R. Dyer, and D.A. Huntley, 1994: INSSEV: An instrument to measure the size and settling velocity of flocs in situ. *Marine Geology, 117,* 107-117.

Fowler, S.W. and G.A. Knauer, 1986: Role of large particles in the transport of elements and organic compounds through the oceanic water column. *Progress in Oceanography, 16,* 147-194.

Gonzalez, E.A. and P.S. Hill, in press: A method for estimating the flocculation time of monodispersed sediment suspensions. *Deep-Sea Research I.*

Gustafsson, O., K.O. Buesseler, W.R. Geyer, S.B. Moran, and P.M. Gschwend, 1998: An assessment of the relative importance of horizontal and vertical transport of particle-reactive chemicals in the coastal ocean. *Continental Shelf Research, 18,* 805-829.

Hill, P.S., 1996: Sectional and discrete representations of floc breakage in agitated supensions. *Deep-Sea Research I, 43(5),* 679-702.

Hill, P.S., J.P. Syvitski, E.A. Cowan, and R.D. Powell, 1998. In situ observations of floc settling velocities in Glacier Bay, Alaska. *Marine Geology, 145,* 85-94.

Hill, P.S., G. Voulgaris, and J.H. Trowbridge, submitted: Controls on floc size in a continental shelf bottom boundary layer. *Continental Shelf Research.*

Honjo, S., 1982: Seasonality and interaction of biogenic and lithogenic particulate flux at the Panama Basin, *Science, 218,* 883-884.

Jackson, G.A., 1995: Comparing observed changes in particle size spectra with those predicted using coagulation theory. *Deep-Sea Research II, 42(1),* 159-184.

Kranck, K., 1984: Grain-size characteristics of turbidities. In: *Fine-grained sediments: deep water processes and facies,* D.A.V. Stow and D.J.W. Piper (eds), Blackwell Scientific Publications, Oxford, 83-92.

Kranck, K. and T.G. Milligan, 1991: Grain size in oceanography. In: *Principles, methods, and application of particle size analysis,* J.P.M. Syvitski (ed), Cambridge University Press, 332-345.

Kranck, K. and T.G. Milligan, 1992: Characteristics of suspended particles at an 11-hour anchor station in San Francisco Bay, California. *Journal of Geophysical Research, 97(C7),* 11,373-11,382.

Lavelle, J.W., 1993: A model for estuarine sedimentation involving marine snow. In: *Nearshore and Estuarine Cohesive Sediment Transport, Coastal and Estuarine Studies Series, v. 42, A.J. Mehta (ed),* American Geophysical Union, Washington, 148-166.

Leuttich, R.A.J., J.T. Wells and S.-Y. Kim, 1993: In situ variability of large aggregates: Preliminary results on the effects of shear. In: *Nearshore and Estuarine Cohesive Sediment Transport Coastal and Estuarine Studies Series, v. 42,* Mehta A.J. (ed.), American Geophysical Union, Washington, 447-466.

McCave, I.N., B. Manighetti, and S.G. Robinson, 1995: Sortable silt and fine sediment size/composition: Parameters for palaeocurrent speed and palaeoceanography. *Paleoceanography, 10(3),* 593-610.

Milligan, T.G., 1995: An examination of the settling behaviour of a flocculated suspension. *Netherlands Journal of Sea Research, 33(2),* 163-171.

Milligan, T.G., and P.S. Hill, 1998: A laboratory assessment of the relative importance of turbulence, particle composition, and concentration in limiting maximal floc size. *Journal of Sea Research, 39(3/4),* 227-241.

Milligan T.G. and D.H. Loring, 1997: The effect of flocculation on bottom sediment size distributions in coastal inlets and its implication for contaminant transport. *Water Air and Soil Pollution, 99(1),* 33-42.

Ruiz, J. and A. Izquierdo, 1997: A simple model for the break-up of marine aggregates by turbulent shear. *Oceanologica Acta, 20(4),* 597-606.

Sternberg, R.W., I. Berhane, and A.S. Ogston, in press: Measurement of size and setting velocity of suspended aggreates on the northern California continental shelf. *Marine Geology.*

Suess, E., 1980: Particulate organic carbon flux in the oceans—surface productivity and oxygen utilization. *Nature, 288,* 260-263.

Syvitski, J.P.M., K.W. Asprey, and K.W.G. Le Blanc , 1995: In situ characteristics of particles settling within a deep-water estuary. *Deep-Sea Research, II 42(1),* 223-256.

ten Brinke, W.B.M., 1994: Settling velocities of mud aggregates in the Oosterschelde tidal basin (the Netherlands), determined by a submersible video system. *Estuarine Coastal and Shelf Science, 39,* 549-564.

van Leussen, W. and J.M. Cornelisse, 1993: The role of large aggregates in estuarine fine-gained sediment dynamics. In: *Nearshore and Estuarine Cohesive Sediment Transport,* Mehta, A.J., (ed.) American Geophysical Union, Washington D.C., 75-91.

Ocean Data View 4.0

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ABSTRACT

Ocean Data View, a multiple-variable graphical analysis and display package for oceanographic station data (station metadata, temperature, salinity, nutrients, others), compatible with several commonly used international marine data formats, is reviewed. Standard derived variables or those based on user-provided formulas can be displayed. Station charts, station data profiles, multi-variable scatter plats, section profiles, and surface plots (one variable plotted on a specific value of any other variable) can be created easily within a user-specified physical layout of Cartesian frames. Plotted data is easily gridded and/or contoured in nearly all views.

The Holy Grail of oceanware, a really good, five-cent Windows data browser, has finally appeared: Ocean Data View! When word spread this past winter that Reiner Schlitzer at the Alfred Wegener Institute-Bremerhaven had released a sensational new graphic program for marine data (http://www.awi-bremerhaven.de/GPH/ODV/), this reviewer wasted no time in downloading and testing it. My intention was just to see if it really worked, and — if so — could it handle some of the analysis and quality control lessons we offer in Intergovernmental Oceanographic Commission (IOC) training classes. Ocean Data View (ODV), now on version 4.0.4, turned out to be a powerful, versatile, yet easy-to-use package that instantly transforms this klutziest of users into a savvy hydrographer (well, almost). ODV is now my program of choice — its overall design, simplicity, capabilities and compatibilities set a high water mark in oceanware that will be hard to match.

I've heard about folks who are absolutely addicted to another browser, OceanAtlas (Swift, J. et al; http://odf.ucsd.edu/OceanAtlas/), and have seen the outstanding examples of its work in Mattias Tomczak's web-published lecture notes (http://gaea.es.flinders-.edu.au/~mattom/ES1/contents.html). But the OceanAtlas is a Macintosh application, vaguely descended from Peter Rhines' old PC ATLAST (http://podaac.jpl.nasa.gov:2031/dataset_docs/ATLAST.html) which sprang from the Living Ocean Atlas of Stommel. Reading the literature on OceanAtlas certainly convinces me that it might be a terrific mousetrap, but alas I am a PC-head, son of a PC-head, and will never know.

Although, as I said, you never really see what's going on "inside" ODV's obviously very robust data model, the capabilities for producing graphical analyses are vast. The "data collection" (the author's term to describe all data currently combined from various sources into an internally consistent, memory-resident, integrated database) available to ODV includes the usual cruise, station, sample, and measurement fields. These can be sliced and diced in an almost limitless way, by mapping selected fields against the X and Y axes in a Cartesian coordinate system. The Z axis (if needed) is represented by the color-coding schema for the X-Y data points, resulting in plots similar to those from ATLAST. Distance along cruise tracks (or latitude, or longitude) can be an axis, resulting in section plots; time can be an axis, resulting in time-series analyses. [The ease of cutting the data into useful X-Y planes (or X-Y-Z spaces) from the inherent n-dimensional dataset reminds this reviewer of the ever-popular Grid Analysis and Display System (GrADS) meteorology data program (http://grads.iges.org/grads/), which by the way is out now in new Windows versions (!). In fact, I'd probably be recommending various kluges between ocean data and GrADS, if its data format requirements weren't so . . . well . . . intellectual.]

There are three very special capabilities in ODV that extend the above analytical model in powerful ways:

- The user can select from a wide suite of "canned" derived variables (including the depth derivative) to supplement the measured variables. These new fields are added instantly to the data collection. In the most recent version of the program, geostrophic velocities can be calculated from appropriate survey transects; the new values are used to populate a new "virtual" data collection tied to the original data and displayed separately.
- When the X-Y plane is selected such that X=longitude and Y=latitude (i.e. the Cartesian graph is also a map), then the user can plot a third variable (the Z variable) on any selected "surface". Surfaces are spe-

cific values of another variable. For instance, you can plot oxygen on the 18-degree temperature surface.

- There is a macro capability, yet unexplored by this reviewer, based on a higher-order syntax defined in the on-line HELP facility.

Additional bells and whistles are also provided to enhance the visual impact of the charts. The default, low-resolution global coastline (ca. 1:20,000,000) can be replaced by "high resolution" versions (ca. 1:1,000,000) for the globe or for the Mediterranean. The old ETOPO5 bathymetry (http://www.ngdc.noaa.gov/mgg/global/global.html) is present for bottom depiction in sections. In the graphing department, all kinds of nifty things can be done to the gridded data depictions, such as contour lines, grid coarseness control, error limits, and data-point notation. The overall menu is far too rich to cover here.

So, ODV can make all kinds of graphs, but with all this power are we locked into specific variables combinations or prescribed layouts? Are flexibility and control sacrificed in order to bring us this rich menu of possibilities? Author Schlitzer has kindly thought of everything, so the user enjoys as many display options as the underlying analytical tools. First, in any display mode, the user can instantly switch any variable along any axis; this permits rapid scanning through all sorts of multiple-property graphs with a view toward quick quality control, or water mass assessment. Second, the user can switch into a graphical layout screen that permits moving, re-sizing, adding, or deleting graphs. Third, the color-scale for the Z-variable can be expanded or contracted to suit the data better. An eerily consistent logic is at work, so that any changes to the color scale or to the range of any axis cascade through the other relevant graphs, all automatically.

This all sounds very tempting, but how much trouble is it to enter the data in which I was really interested?

Several templates for the ODV "data collection" exist, such as the variable set in the World Data Center A's new World Ocean Database 98 (WOD98; http://www.nodc.noaa.gov/OC5/index.html) or the variable set in the traditional SD2 exchange format (http://www.nodc.noaa.gov/NODC-Archive/sd2.htm). Even the regrettable "mass-per-mass" WOCE data units (http://whpo.ucsd.edu/manuals.htm) are on the list, an act of supreme charity one would think, considering WOCE's apostasy in these matters. [The reviewer is an ICES true believer.] Into any template, the user can load data from several or many different recognized formats. But, be careful you don't use a template that omits an analyte of interest; for instance, don't use the SD2 template if you want to load chlorophyll data. The recognized import formats are: World Ocean Atlas 94, WOD98, SD2, WOCE, ODV's own hierarchical ASCII format, and ODV's own ASCII spreadsheet format. There is an ingenious function that matches up the incoming variables with the template variables (based on the field names), and even performs necessary conversions when needed. The troublesome mass-per-mass variables can be handled in this way.

Data importing is aided by a well-designed set of filters to impose time, geographic, quality, source, or type limits on incoming data. This same filter is, however, always available during the graphing process, so the user can safely import the maximum amount of data initially. Veteran users of ODV who may wonder why I have not mentioned unzipping the WOD98 files will be happy to know that the current version does this automatically, which brings up a good point: Schlitzer has posted several updates to the program with little fanfare, so sign up for his mail list to receive update notices.

So how good is Ocean Data View, really?

From the very parochial perspective of the OceanPC software project (http://www.ices.dk/ocean/oceanpc.htm), where we desperately need a well-documented, Windows graphical engine to replace ATLAST, ODV offers a wide range of attractive analytical tools that are immediately grasped by students in developing countries. We can take regional data straight from WOD98, and have the students making rather sophisticated graphs in minutes. The next step, adding local data for national–and institutional–level projects, is obvious, and — what's more important – made attractive by the simplicity of the import routines. One attractive route would be raw data entry with OceanPC, then use of OceanPC's new ODV export routine. We hope eventually in the International Oceanographic Data and Information Exchange (IODE) community to reap a large fraction of these additional data, because they have already necessarily been converted to a "standard" format during the process. From this point of view, ODV is the Great Carrot, thanks to the good Professor Schlitzer.

From the broader perspective of students and professionals everywhere, ODV is definitely the best freebie around. Although there are some tricks you need to learn to get CD datasets into the system (for instance, there are various routes from WOD98 to ODV), the compatibility with other information models is inspiring. Author Schlitzer has incorporated important existing formats, and kept his own format-craft to a necessary minimum, a commendable restraint that we could use more of. Further, he has achieved a reputation for near-instant upgrades in response to user requests and comments. One very recent upgrade was the addition of the WOD98 format; another was explicit logging of user corrections to the data (yes, edits are possible too!). Carefully working within the context of existing widgets when they are good, but imaginatively creating new ones when they are lacking, is the crowning achievement here. That, plus the very professional

"look and feel" of the program screens, menus, and documents. Don't miss a very good thing . . . add Ocean Data View to your software collection ASAP.

SUPPLEMENTAL INFORMATION:

How To Obtain: Web address, http://www.awi-bremerhaven.de/GPH/ODV/. Make sure to sign up for the mail list of users, because frequent updates occur without any other notice.

What to Obtain: ODV40.ZIP (2252K), ETOPO.ZIP (1416K), GLOBHR (2740K), MEDHR.ZIP (236K), WOCEBTL.ZIP (3535K).

Installation Tips: Install optional zipfiles from the recommended C:\ODV40 directory, not from C:\TEMP.

What Goes In: World Ocean Atlas 94, World Ocean Database 98, WOCE hydrographic program (bottle or CTD), SD2, and (via conversions) ICES standard profile databases; ASCII hierarchical data file; ASCII spreadsheet data file.

What Comes Out: PostScript files, GIF files, ASCII files of data points currently plotted (undocumented formats); ASCII file of data in currently selected stations (ODV-specific formats .03X and .04X); ASCII spreadsheet data file.

Operation Tips: The SD2 import routine in ODV may not work with SD2 files on NODC CD-ROM 20 ("Long Time Series"). Use the OceanPC software to convert SD2 files to comma-separated version (CSV); then use the special CSV-ODV program from ICES to convert CSV to ODV format. To put new data into ODV, use the OceanPC CSV spreadsheet format to create the file(s) and perform preliminary data quality control with OceanPC routines; then convert the final CSV file with the CSV-ODV program from ICES. Occasional glitches in the graphics screens can be overcome by switching the display away from and back to the desired mode.

Documentation & Help: Excellent hyperlinked, HELP-type documentation. Export of ASCII values of currently plotted data points needs better format documentation. Other issues are dealt with quickly by direct contact with the author at the web address.

Report on TOS Meeting in Paris, June 1 - 4 1998

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I Love Paris
(with apologies to Cole Porter)

I love Paris in the springtime,
I love Paris most of all,
I love Paris for the science, at UNESCO,
I love Paris at TOS meetings, where the best go,
I love Paris and the ocean,
Ocean science is so fair,
I love Paris,
Why, oh, why do I love Paris,
Because our TOS is there.

The Oceanography Society is an international society, with approximately one-quarter of its membership from outside the United States. One of the strategic goals of TOS is to increase its non-North American membership, in recognition of ocean science as a topic that knows no national boundaries and consistent with the interdisciplinary and inclusive nature of the subject.

To this end, the 1998 Annual Meeting of TOS was held in Paris, jointly sponsored by the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific, and Cultural Organization (UNESCO). IOC (see http://www.unesco.org/ioc/) has 125 member states, all on the ocean, and all interested in furthering the science of the ocean and its wise application to the use and conservation of the ocean, its boundaries, and its resources. The meeting was also co-sponsored by the American Geophysical Union (AGU), the American Meteorological Society (AMS), the American Society of Limnology and Oceanography (ASLO), the Canadian Meteorological and Oceanographic Society (CMOS), the Challenger Society for Marine Science (CSMS), and the Marine Technology Society (MTS). Of note is that over 60% of the speakers, chairs, and attendees were from non-North American locations.

The meeting co-chairs were Dr. Kenneth Brink from the Woods Hole Oceanographic Institution in Massachusetts, U.S.A., and Dr. Katherine Richardson from the University of Arhus, in Denmark. Full details of the sessions, speakers, abstracts, and posters can be found in this issue of *Oceanography*. In summary, the focus of the meeting was "Coastal and Marginal Seas," and the sessions were structured around Small Scale Processes, Medium Scale Processes and GOOS, Regional Scale Processes, and Policy and Late-Breaking Events. Each session was one half day.

Total attendance was 227 (including 14 students), what some call a small meeting, others call intimate. To encourage the student attendance, TOS offered half-price registration and abstract fees for students. In addition, the Office of Naval Research (ONR) and the National Oceanic and Atmospheric Administration (NOAA) provided travel support and hosted two groups of Mentor-Plus-Students from the University of Alaska (Fairbanks) and Texas A&M University (Corpus Christi); the students were Native Americans (U of AK) and Hispanics (TAMU).

One senior attendee commented afterwards to me that he wished he'd been able to go to a meeting like that when he was a young scientist, because during his early career he'd never had the opportunity to speak directly with so many famous scientists and actually have a chance to discuss things with them at a poster session of manageable size, or even go out to dinner with them. His words took me back to an International Association for the Physical Sciences of the Ocean (IAPSO) meeting on North Atlantic Variability that was held in Dublin in 1968, while I was a post-doc at the NATO SACLANT laboratory in La Spezia, Italy. It was a meeting of similar size to the TOS Paris meeting, and

had a similar number of international and recognized scientists present. It was a marvelous and exciting experience that helped shape my career, and it also introduced me to draft Guinness with Dublin Bay oysters and Irish brown bread slathered with butter; a terrific meeting.

Most of the presentations, posters, and graphics were excellent at the TOS Paris meeting, as is the usual high standard for TOS, although a few did not reach the mark. Back in 1987-88 when TOS was being formed, one of the strong motivations was to raise the standard of ocean meetings and to demonstrate by example how to give a good scientific talk and present a good poster paper. I have not met anyone who was at the first TOS meeting in Monterey in 1989 who does not remember vividly one or more of the talks by Munk, Stommel, Packard, or others. The excitement was palpable. Several of the TOS Paris presentations were of that high standard, for example:

- Mimi Koehl's lively talk on small-scale hydrodynamics of zooplankton will be remembered by all who were there, both for its content and for its presentation.
- Chuck Nittrouer's tour de force in describing the broad interdisciplinary work on the Amazon discharge was an exemplary demonstration of how to cover much without getting mired in details or in one's own favorite parts.
- We have been hearing about the Global Ocean Observing System (GOOS) for a decade now, without much apparent substance, but Neville Smith provided an intriguing, tractable, and important objective in the Global Ocean Data Assimilation Experiment (GODAE), while Nick Flemming gave clear evidence that EUROGOOS is actually happening, data are flowing, products are being produced, and the value of the research and observational investments are being realized.
- Patricio Bernal, the Executive Secretary of the IOC, challenged our thinking and complacency, with comments like, "The scientific agenda is being driven by society. We are not comfortable with this." Or, "We are a guild. We operate with our own rules of self-recognition and structure, as in a guild." And finally, to help explain his IOC, "Intergovernmental organizations try to give a structure to the demands of society, to try and develop good communication with the specialized guilds."

As I have pointed out in other meeting reports in *Oceanography*, people have really figured out how to prepare and present posters. At a TOS meeting, with only a few oral presentations, communication of one's science by use of posters is even more important. With the ready access to color graphics and large printers, however, it is more apparent than ever that a few of the posters have no point, no punch line, no conclusion, no insights. Ocean sciences has always been plagued with papers that do no more than say "here is what I did and what I measured," and leave you hungry for why it was done, or what was learned, or what insights were gained, or how it fits together with other efforts and other data. Partly this has been a consequence of how very difficult it is to obtain quality data from the ocean, so simply having some to show was a major achievement. (I remember when one could publish the wiggly line from a current meter, because no one had seen one before...) We are beyond that, in most cases. The posters need to use the beautiful graphics to help show why the problem was tackled, and what the insights and lessons learned were, and why someone might care, and what comes next. I don't mean to imply the TOS Paris poster sessions were poor; quite the contrary. They were superb overall, which only meant that the posters that were lacking stood out more than usual.

I believe the TOS meeting format of long, invited, plenary talks designed for interdisciplinary audiences, combined with contributed posters designed for one-on-one interactions, proved itself again as a superb format for scientific communication within the broad topical areas of oceanography. Even though not every person attending has the opportunity to talk to a large audience, they all do have the opportunity to use a poster to display their work, and they have the opportunity to listen and learn about subjects outside their own specialities.

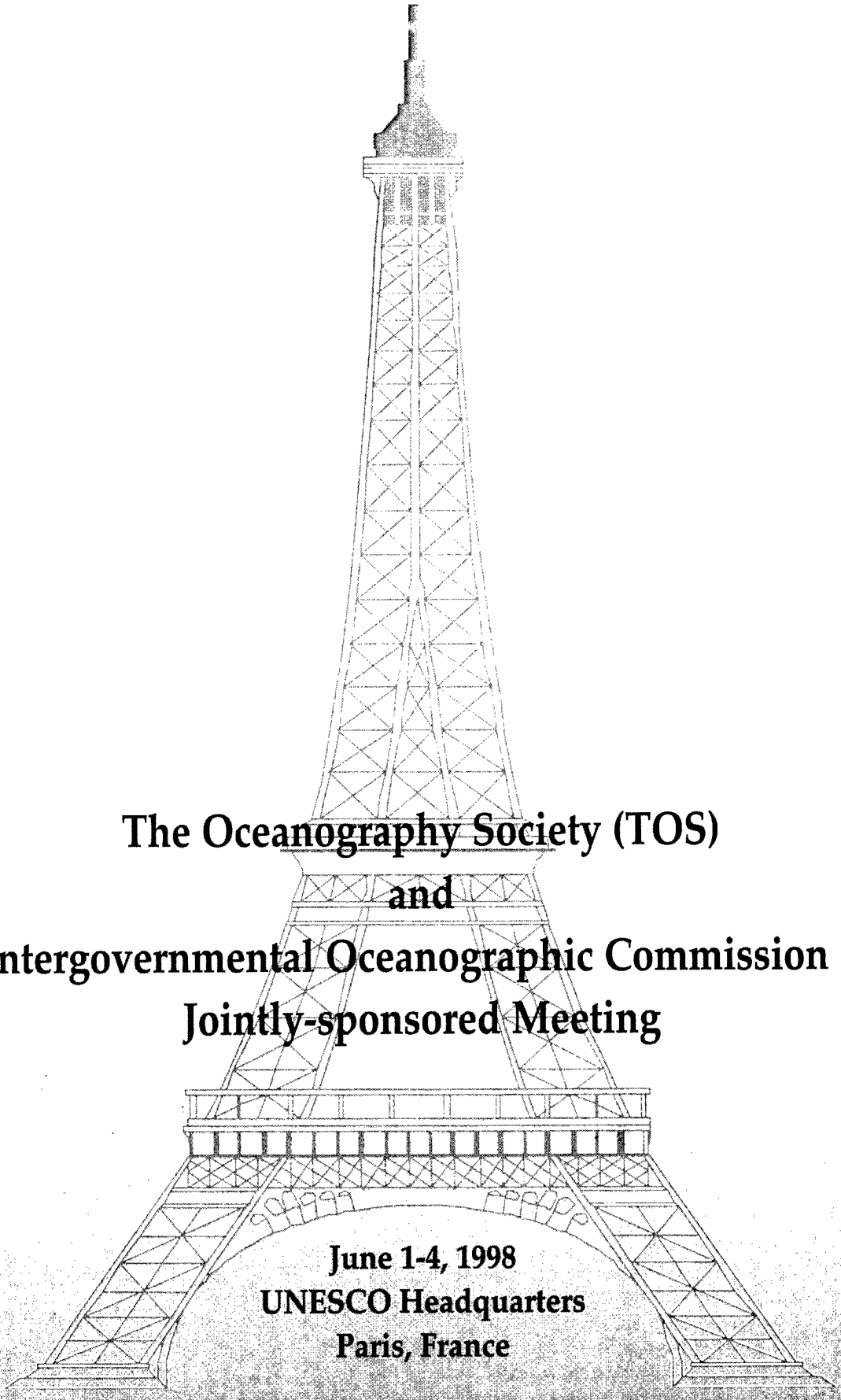
So was it a good meeting? My favorite criteria (in no special order) are:

- Did I learn something new? (Yes)
- Was I challenged intellectually? (Yes)
- Were the talks and posters of high quality and professional? (Yes)
- Did I meet some old friends? (Yes)
- Did I meet some new folks, whom I look forward to seeing again? (Yes)
- Was I able to press some issues/topics I care about on some people who seemed interested? (Yes)
- Was the food good? (Yes!!)
- Was the site interesting (Yes!)
- Am I glad I spent the time and money? (Yes!)

Others may have different criteria. But here is a quote TOS received afterwards: "The Paris meeting served as my first introduction to TOS. The meeting was indeed a major success. The quality of the talks and posters was extraordinary...I appreciated the opportunity to present [a poster] at the meeting and now that I am a member I hope to attend many more."

It was, in fact, a terrific meeting. The TOS Council plans to consider returning to Paris and UNESCO perhaps every three years, in a continued effort to remain an international society and to retain a bond with the IOC. I look forward to TOS Paris in 2001; I hope at least 500 people go the meeting, because there are at least 500 oceanographers who will find they are glad they spent the time and the money.

Paris Abstracts



The Oceanography Society (TOS)
and
The Intergovernmental Oceanographic Commission (IOC)
Jointly-sponsored Meeting

June 1-4, 1998
UNESCO Headquarters
Paris, France

SMALL SCALE PROCESSES (SSP)

SSP-01: Applying coagulation theory to understand oceanic particle dynamics

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Particle processes control the chemistry of the ocean. Particularly important is particles' ability to fall through the water column, carrying associated chemical constituents with them. Particle settling speed is greatly controlled by particle size, with larger particles tending to fall faster. While earlier work has focussed on the role of grazers in packaging small organisms into faster sinking fecal pellets, our present understanding is that amorphous aggregates formed by a combination of physical, chemical and biological processes are the dominant agent of particle transport. Coagulation theory, in which physical processes control collision rates, provides the starting point for studying the formation of aggregates. One success of this approach has been the prediction of maximum phytoplankton concentrations. The further application of coagulation theory to understand particle dynamics requires its modification and extension to include greater incorporation of biological and chemical aspects of the marine environment, including multiple particle sources, chemical adsorption kinetics, and biological interactions. Experimental tests will require characterization of particles in terms of multiple properties. The goal of these studies of the micro-scale processes is a more complete understanding of vertical transport of material in the larger ocean.

SSP-02: Limits on Floc Size in the Coastal Ocean

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The majority of particles in the sea reside in large particle aggregates, also known as flocs. Observations indicate that there are limits to floc size. For example, observed and estimated floc sinking speeds rarely exceed a few millimeters per second (100–200 meters per day), and maximal diameters typically fall in the range of 1–10 mm. The conventional view identifies forces imposed by turbulence as responsible for limiting floc size, yet this view does not explain why flocs from diverse environments sink at similar speeds. Further, recent observations of floc size in a continental-shelf bottom boundary layer and in a buoyant, turbid river discharge plume suggest that predicted and observed dependences of maximal floc size on turbulent-kinetic-energy (tke) dissipation rate differ significantly. Rather than showing a power-law dependence of maximal size on tke dissipation rate, these data indicate that floc size depends only weakly on tke dissipation rate at low to moderate energy levels, but at high energy levels maximal floc size decreases abruptly. These observations suggest that at low-to-moderate tke dissipation rates, forces imposed by the relative particle-fluid flow generated by sinking limit floc size. Scale analysis supports this hypothesis and predicts that turbulence affects floc size at dissipation rates similar to those observed to produce a dramatic reduction in in situ particle diameters in both studies. These new ideas regarding limits to floc growth will simplify the modelling of flocs in the sea.

SSP-03: Diffusion limitation in the pelagic environment

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Diffusive boundary layers (DBLs) with concentration gradients of solutes develop at small scale and at interfaces, where molecular diffusion is fast compared to advection. Small free-living organisms as well as aggregates composed of phytoplankton and other microorganisms are surrounded by a DBL on a sub-millimeter scale in the pelagic environment. The concentration gradients in the DBL depend on the diffusive fluxes due to nutrient and gas exchange between the organisms and the surrounding water. It is not clear to what extent the pelagic processes are limited by the DBL thickness surrounding the organisms. Diffusion limitation of the biological processes depends on sizes and biological activities of the organisms or aggregates, and on the shear and concentration levels of nutrients and gases in the environment. Microscale gradients of oxygen concentrations within and around 0.5-5.0 mm large sinking aggregates have been measured using microelectrodes in a custom-designed flow system. The aggregates were kept in suspension by an upward flow velocity, which balanced their sinking velocities. The impact of advection in the vicinity of sinking aggregates was determined by flow visualization techniques. The DBL thickness and the biological activities were reflected by the microscale gradients of oxygen concentrations measured at different sinking velocities. DBLs and diffusion limitation will be discussed and illustrated with examples from recent empirical studies and model calculations.

SSP-04: Small scale solute dynamics at the benthic interface

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The use of microsensors has during the last two decades significantly increased our knowledge about the benthic

interface. In combination with traditional incubations techniques, microsensor data have documented the importance of coastal sediments in remineralization and in primary production. The intense biogeochemical cycling in surface sediments results in a dynamic exchange of solutes across the benthic interface where microsensor measurements have demonstrated the existence and importance of the diffusive boundary layer. However, at the scale of microorganisms the benthic interface has proven to be very heterogeneous and an extensive variability in solute dynamics has been shown to occur. At a 3-dimensional interface, the one-dimensional approach of microsensors and the traditional incubation techniques only to a very limited extend allow the heterogeneous structure of benthic communities and the associated solute dynamics to be resolved. The recent introduction of planar sensors and image technology to the field of microbial ecology has greatly improved our ability to study the benthic solute dynamics. The combined use of microsensors, planar optodes and imaging has given new insight in the organization and structure of microbial communities. Recent data on small scale solute dynamics at various benthic interfaces will be discussed in the context of microenvironments and microbial community structure.

SSP-05: The implications of biologically and physically created fluid motion on the sensory horizon of copepods

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Copepods live in a fluid medium. Their ability to move, feed and detect biologically important signals is governed, in part, by the physical properties of the fluid. Most planktonic copepods generate laminar flow feeding currents to entrain water over their sensory receptors and into their capture region. The feeding current creates an organized fluid environment which enables these blind animals to accurately respond to both mechanical and chemical signals. Recent data suggest that the structure of the flow field can facilitate the ability of copepods to detect and capture different types of prey. During this talk I will present data on the feeding currents of three copepod species. The implications of the structure will be discussed in light of the larger ecological context of these animals. The organized structure of the feeding current is in direct contrast to the random nature of the background turbulence. Shear within the feeding currents was found to be comparable in magnitude to that caused by normal to high energy dissipation rates. This suggests that the extension of the organized feeding current may be considerably smaller in nature than those measured in typical laboratory conditions. Since copepods rely on the structure of their feeding currents to give information pertaining to the presence of predators and prey, interference of the feeding current functions by turbulence may limit animals to particular environments. These results suggest that the zonation of copepods in both their vertical and horizontal positioning may be modified by the disruption of the feeding current structure by environmental turbulence.

SSP-06: Small Scale Hydrodynamics of Particle and Odorant Capture by Animals

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Many marine animals use appendages bearing arrays of hairs to capture food or molecules from the surrounding fluid, or to locomote or create currents past themselves. The performance of these functions by hair-bearing appendages depends on how much of the fluid that they encounter flows through the gaps between the hairs rather than around the perimeter of the whole array. We have conducted high-speed kinematic analyses of various hair-bearing structures (e.g. particle-capturing appendages of copepods; olfactory antennae of various crustaceans) and have used these data to design dynamically-scaled physical models. We have used flow visualizations around the physical models as well as mathematical models to elucidate the factors that determine the leakiness of an array of hairs. Our work has revealed that different aspects of morphology and behavior are important in determining the performance of hairy appendages at different Reynolds numbers.

SSP-07: Coastal Waves Observed by Radar from an Airship

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Recently, an airship instrumented with an X-band coherent radar having a rotating antenna was flown off the Pacific Coast of Oregon. Quantities related to small-scale surface roughness, line-of-sight surface velocity, and the variance of this velocity were obtained by the radar and recorded. The antenna could be operated in either a rotating or fixed mode. In the fixed mode, images of the recorded quantities could be produced while in the rotating mode values of these quantities in different directions were recorded. The images clearly showed long surface waves propagating toward the beach and their refraction as they approached the beach. Furthermore, the imagery showed signatures of internal waves and their interaction with surface waves.

From both the rotating and imaging mode, directional wave spectra were obtained which were slightly different in the two cases. In the case of imagery, the wave height variance spectrum as a function of cross-track wavenumber and encounter frequency was obtained while in the rotating mode, this spectrum was obtained as a function of along and cross-track wavenumber. Thus peaks in the spectrum appeared at clearly defined positions in wavenumber/frequency space and their dispersion relationships could be inferred. Several of the data sets showed evidence of waves propagating off the first-order dispersion relationship. We suggest that these waves are evidence of waves produced by nonlinear wave-wave interactions which are difficult to observe in standard spectra measured by buoys, wavestaff arrays, fast aircraft, or spacecraft.

SSP-08: Modelling the Near-Surface Circulation with the Mellor-Yamada Turbulence Closure Scheme

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Knight Inlet, British Columbia is a long (≈ 90 km), narrow (≈ 2 km) coastal fjord in which the tides, the winds and freshwater runoff all have a significant influence on the circulation. The influence of the winds is particularly noticeable on the subtidal, near-surface circulation. A two-dimensional numerical model of Knight Inlet that uses the Mellor-Yamada level-2.5 turbulence closure scheme has been compared to month long observations of horizontal velocity and density that were made as shallow as 2m from the surface. The model produces realistic simulations of the circulation throughout the water column, but it is found that the near-surface simulation is significantly improved if the surface boundary condition for the turbulent velocity scale is changed from that which is normally used in the Mellor-Yamada scheme, i.e., q^2-$B_1^{2/3}u_*^2$, where is a constant and is the friction velocity, to one which specifies the flux of q^2, i.e., $\lambda_V \partial(q^2/2)/\partial z - au_*^3$ where λ_V is the vertical diffusion coefficient for the turbulent kinetic energy and $a \approx O(10^2)$ is a constant. With this flux boundary condition, both the mean velocity and density profiles, and the subtidal variability in the velocity field near the surface are better simulated. The surface roughness length has also been estimated by expressing it as, where g is the acceleration due to gravity and is a constant. It is found that ≈ O(105), for the data set from Knight Inlet. Comparison of this expression for z_0 [with $a \approx O(105)$] with empirical expressions for the significant wave height H_s, yields $z_0 \approx Hs$.

SSP-09: The similarity of internal wave properties in the North Sea during strongly stratified and 'unstratified' periods

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The interior of the ocean is known to be generally 'stably stratified' in density, which partially determines the large scale dynamics and, on smaller scales, the attenuation of mixing of momentum and mass. It is remarkable however, how robust a semi-empirically derived description exists today of the oceanographic spectrum in the 'internal wave band' (Garrett and Munk, 1972). The canonicity of this description holds especially for the spectral shape of the internal wave band (defined between the inertial frequency f and the buoyancy frequency N), with, despite numerous observational attempts, only a few exceptions. I will present internal wave spectra from two apparently completely different regimes, based on ADCP observations from a single location in the central North Sea, with data from summer and winter periods. During the summer period the area is strongly stratified, while it is known to be 'well-mixed' from surface to bottom during winter, due to increased levels of atmospherically induced mixing. It will be shown that, despite the entirely different surface forcing through wind and waves between summer and winter, the internal wave band is negligibly different over the year. Furthermore, it will be shown that one may question in general the absence of stratification during winter in an internal wave sense.

Garrett, C.J.R. and W.H. Munk. 1972. Space-time scales of internal waves. Geophys. Fluid Dyn., 3, 225-264.

SSP-10: Strong Tide-induced Vertical Mixing in a Deep Fjord with a Shallow Sill

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The 20 km long fjord Lurefjord is located on the West coast of Norway. The maximum basin depth is 450 m and the sill depth is 20 m. Theoretically the topography should make the fjord susceptible to temporary oxygen depletion in the basin water. However, no such depletion seems to occur. In 1990 investigations were initiated to explore what are the main mechanisms contributing to the water renewal. The hydrographic observations revealed some spectacular internal waves of semidiurnal tidal period, with the largest observed

vertical excursions of 25 m confined to the pycnocline slightly below the sill depth. It is concluded that the internal tide is playing a major role in the process of vertical mixing and aeration of the intermediate and deep water of the Lurefjord. A water quality model predicted total oxygen depletion in the basin water, probably due to an underestimation of the vertical mixing. The poster presents highlights of the observational findings, suggests an explanation of the vertical mixing and presents suggestions on how to improve models.

SSP-11: Fine- and Microstructure Measurement Systems Developed in the Japanese GOOS

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In order to measure oceanic turbulence and to parameterize turbulent diffusion coefficient in the ocean, a towed Temperature Structure Profiler (TSP) and a Fine- and MicroScale Profiler (FMSP) were developed during the Japanese GOOS Project. The TSP can measure fine-scale temperature structure in the surface layer down to 200m depth with the 27m long vertical sensor array of 54 sensors mounted on a 13p electric line with 50cm intervals. The system enables us to visualize fine-scale temperature structure and internal wave pattern including wave breaking. The FMSP is a combined system of a MicroStructure Profiler and a Freefalling Electro-Magnetic Current Profiler already developed separately. The FMSP can measure vertical profiles of temperature, conductivity, horizontal currents (fine-scale shear) and microscale shear simultaneously for the maximum depth range to 500m as it descends. An outline of the systems and several examples measured ony the above systems are presented.

SSP-12: Studies of Mixing on the Continental Shelf

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Physical microstructure signals were collected on the continental shelf south of New England with a new towed microconductivity system. Measurements were made at 70 m nominal depth in the summertime, and show weaker diapycnal diffusivity than in the open-ocean thermocline. Results agree with diffusivity estimated from dye dispersal experiments in this region. A tow-yo section provides cross-isopycnal diffusivity estimates in many types of stratification. These can be compared with the dye experiment results, which are very accurate but pertain to a limited volume of water. In the section, turbulent diffusivity averages 20 times the molecular diffusivity of heat, one-fifth of a typical pelagic value. The average buoyancy frequency was near 16 cph. Diffusivity was seen to decrease with increasing N. No clear distinction between diffusivities under stable, diffusive layering, and salt-finger favorable conditions has been established. In addition to the section, eleven microstructure tows were made within a few meters of the bottom, in and above an intrusion of warm salty bottom layer creeping shoreward. Diffusivity was low in the strong gradient layer above the intrusion, allowing it to move far shoreward, making the foot of the shelf-break front nearly flat. Diffusivity was up to 1000 times molecular in the layer, averaging about 100 times molecular. The new rapid-sampling conductivity system was incorporated into a new dye sampling system. System design and performance information will be included.

SSP-13: Near-surface turbulence in a wind-driven sea

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Turbulence near the ocean surface is the link between vertical transfer at the air-sea interface and the deeper advective field. At high sea states in the open ocean detailed measurement of this turbulent field presents an interesting observational challenge. We exploit heat as a passive tracer of near-surface turbulent diffusion. A freely drifting temperature profiler was used to acquire near-surface profiles in a storm. Independent measurements of heat flux provide the essential basis for interpreting the measured temperature gradients and calculating the turbulent diffusivity. The length scale of turbulence elements, obtained from the temperature profiles, increases with depth. This provides the basis for a mixing length model which predicts a near surface layer of enhanced turbulence. Advection due to Langmuir circulation also leaves its signature on the near surface temperature field. Both advection and diffusion are reconciled in a 2-dimensional model of the upper ocean boundary layer and different diffusivity parameterizations are evaluated.

SSP-14: Turbulence measurements in laboratory tanks stirred by two different mechanisms

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Several mixing systems for simulating natural aquatic turbulence have been developed recently at UMCES, HPL. One of these systems uses horizontal paddles on a rotating vertical shaft in the center of a tank, similar to several other facilities. Another system uses vertical baffles on the inner wall of an oscillating cylindrical tank to generate turbulence. Flow measurements have been carried out in tanks stirred by both mechanisms. The data reveal some differences between the systems, but a remarkable degree of similarity in their turbulence characteristics. Fluctuating velocity components are larger than mean velocity components in both systems. Both are capable of generating fully developed turbulent flow, with approximately isotropic velocity fluctuations over a well-defined inertial subrange and realistically low energy levels. In both systems, the inertial subrange extends to frequencies (wavenumbers) well below the generating frequency (wavenumber). In both systems, the integral length scale of the turbulence approximates the size of the generation mechanism nearby, but increases with distance away from it. As a consequence, turbulence energy dissipation rates are more spatially variable than turbulence intensities. Spatial uniformity of turbulence characteristics appears to be related to the strength of the internal circulation, which differs between the two designs.

SSP-15: Turbulent energy in a mesocosm

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Recent studies show that turbulence can affect aggregation, nutrition, sedimentation and other algae-processes. In an experiment designed to study these phenomena, turbulence was generated by large grids in eight large bags. Four bags received "high" turbulence, and four bags received "low" turbulence. Each enclosure contained an upper, homogenous layer above a lower, denser layer. In order to keep the density interface at a constant depth, fluid was added below the pycnocline. The upper border of the pycnocline stabilized at 4 meters for the low-turbulent sytems, and at 6 meters for the high-turbulent systems. Turbulent velocities were measured, and dissipation rates calculated. In the ocean, dissipation transfers around 90% of the turbulent energy to internal energy. Efforts will be put on to integrate the total dissipation rates in each enclosure in order to calculate how much energy goes to buoyancy fluxes, compared to the energy that dissipates. A rough estimate indicate a 90% dissipation in the enclosures. Manipulation of the system revealed that when turbulence stopped, the pycnocline moved upward, and when turbulence restarted, the pycnocline was lowered. A decrease in flux below the pycnocline resulted in a lowered pycnocline. The effect on plankton is slightly unclear, but tentative studies show a small increase of biomass in the enclosures with higher energy input.

SSP-16: Diel changes in marine snow abundance in the Santa Barbara Channel (USA): possible controls by vertical migrators

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The discovery of a diel component in marine snow abundance deep (>250 m) within the water column has stimulated interest in resolving the mechanisms responsible for such short-term variability in particle flux. Recent computer simulations have suggested that upper ocean turbulence, and not vertically migrating zooplankton, was the principal mechanism at work. To investigate short time-scale variability of marine snow, we conducted two 24 hr times-series of aggregate profiles in the upper 100 m of the Santa Barbara Channel. We also sampled abundance of euphausiids in the upper 100 m. In the presence of vertically migrating euphausiids, a diel signal was of uniform magnitude and extent throughout the sampled water column. In the absence of euphausiids, marine snow abundance above the thermocline appeared influenced by wind with little variability below the thermocline. Convective overturn did not appear to be a substantial source of turbulent mixing in the upper water column. We argue that large zooplankton are capable of reducing the nightly particle flux through grazing and the disaggregation of larger particles. These data are among the first to provide observational insights into the high-frequency variability of marine snow in the surface ocean.

SSP-17: Marine Snow on the European Continental Slope: Modelling and Observation

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Vertical profiles of marine snow particles (>0.5mm diameter) have been obtained photographically along sections across the continental slope to the west of Britain at 49°N and 56.5°N to determine seasonal, vertical and cross slope trends. The spatial and temporal trends are simulated with a 1-D physical and microplankton-detritus model. The similarity between modelled and observed profiles suggests that to a first order, distributions of marine snow are related to ambient turbulent conditions and microbial remineralisation rates. The model demonstrates a clear seasonal signal which is in contrast to the observations where such trends are surprisingly slight. The reason for this may

simply be inadequate temporal coverage of the observations. Subsurface maxima were a characteristic of both regions in many of the profiles throughout the year and are sometimes a feature of the model output. Discrepancies between modelled and observed profiles indicate that marine snow grazing (not modelled explicitly), may be an important process. Modelled distributions are sensitive to changes in microplankton stickiness and sinking rate and the range of published values for these parameters are explored. Additionally the model is used to test the hypothesis that marine snow sinking rate varies with particle age (indexed to phytodetritus carbon to nitrogen ratio).

SSP-18: Extensive Mucilage Aggregates in the Northern Adriatic: Phenomenological and Biological Characteristics

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Suspended aggregates of different size are ubiquitous in oceans and usually attain higher abundance and mass in coastal regions. Large flocks reaching several centimetres are seasonally abundant in the northern Adriatic and have been generally related to decaying diatom blooms. Extensive mucilage aggregates (several metres in size and affecting areas up to 10,000 km2) that develop sporadically during summer in the northern Adriatic appear to be unique to this area and have serious environmental and socio-economic consequences (tourism, fisheries). In last decade widespread massive accumulation of mucilaginous material has occurred in 1988, 1989, 1991 and 1997; since 1872 researchers reported on six other mucilage events spreading over a large part of the northern Adriatic and 14 more localised ones. Large mucilage aggregates typically appear in late May-early July in mid-water depth where they remain suspended for several weeks at a density discontinuity layer(s). Some aggregates become buoyant and float to the surface, while a minor fraction has been observed to sink to the bottom during the period of water column stratification. Freshly formed aggregates are rather fragile and their biotic components are similar to those in surrounding water. Aged mucilage accumulated at pycnocline(s) has a biological composition that differs from a fresh one, it is more compacted and resistant to degradation. The phenomenon generally dissipates with autumnal destratification of the water column.

SSP-19: Sediment stability and characteristics of resuspended aggregates of the western European continental margin

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Sediment stability and characteristics of resuspended aggregates at different locations at the western European continental margin were experimentally determined on board by means of an image analyses system using a benthic erosion chamber. Sediments at the continental margin (200 to 3600 m water depth) consisted of a surface layer of patchy distributed loose aggregates > 100 μm, which were resuspended under critical shear velocities [u*c] of 0.4 to 0.9 cm s^{-1}. For the underlying sediments, u*c increased from the sandy shelf sediments to the cohesive clay sediments at the continental rise from 0.5 to 1.7 cm s^{-1}. The surface layer aggregates were very stable, could be stored and transferred into a settling cylinder, where an empirical linear settling velocity versus diameter relationship was determined for a temperature range from 2 to 8° C. Experiments and in situ studies with particle cameras and flow sensors demonstrate that under typical flow conditions found at the continental margins, the aggregated surface layer can progressively be transported in resuspension loops over long distances. These resuspension loops can have important implications for the benthos, as the aggregates might serve as an unlimited food source for the interface- and surface deposit feeding macrofauna.

SSP-20: What determines the end-products of nitrate reduction in estuarine sediments: A diagenetic model study

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We describe a quasi-transient diagenetic model developed for an estuarine sediment subjected to high nitrate concentrations (200μM - 1200μM). Five variables (O_2, NO_3^-, NH_4^+, HS^- and $SO_4^=$) are modelled from the observed steady state distribution of organic carbon. Only boundary conditions and temperature change with time. The model is unique in that it contains empirically derived functions based on nitrate concentration and temperature. These determine the end-products of nitrate reduction (i.e. N2 or NH4+). The model has been validated against monthly porewater (r^2>0.9) and sediment exchange rate (r^2>0.9) data. Field and laboratory studies on the direct effect of a particular controlling factor (e.g. temperature) on nitrate reduction are confounded by the fact that the rate is determined by a number of interacting factors (e.g. nutrient levels, nitrification, oxygen, organic carbon, bacterial species). We will examine the direct effect of variations in levels of oxygen and nitrate and in temperature on the rates and end-prod-

ucts of nitrate reduction. This model goes some way in helping to understand what controls the fate of nitrogen in estuarine sediments.

SSP-21: Zooplankton 210-Po Uptake in Relation to Trophic Conditions During a One Year Cycle in Monaco Bay

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Monthly sampling in Monaco Bay (Principality of Monaco) was undertaken to test the hypothesis that, in oligotrophic waters, there is an inverse correlation between zooplankton biomass and 210-Po accumulation as shown by Jeffree et al, (1997) for French Polynesian waters. As expected, a spring zooplankton "bloom" occurred during May, preceded by a sustained increase in particulate organic matter which started at the end of March, and followed a sharp decrease of both in June. No correlation was noted between zooplankton biomass and 210-Po concentration in zooplankton. These two variables appear to be independent in this area; however, zooplankton biomass was never as low as it was in French Polynesia. During the sampling period, there was an opposite trend during the sampling period, between 210-Po in zooplankton and 210-Po in water, however data were too variable and no significant correlation was found. The highest 210-Po concentration in zooplankton coincide with the lowest POM value and the lowest 210-Po in water. Different size classes, different taxonomic groups and different locations showed quite different bioaccumulation capacity and appear to be an important factor which must be considered in the study of the balance of this element.

SSP-22: Vertical distribution of copepod life stages associated with changing turbulence

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We sampled the vertical distribution of turbulent kinetic energy dissipation rates (EPSONDE profiles) and zooplankton (pump/CTD profiles) at a well-mixed and a stratified site on Georges Bank, NW Atlantic Ocean, 8-15 June 1995. Zooplankters at the well mixed site showed no systematic pattern of vertical distributions with Epsilon in the range of 10^{-6} to $10^{-6.5}$ W/kg. At the stratified site, zooplankton were most concentrated in the upper 20 m during calm conditions – above the subsurface chlorophyll maximum when it was present, and above the pycnocline. Highest concentrations occurred at depths of low Epsilon ($5*10^{-7}$ W/kg or lower). During a brief period of wind mixing (24 h with wind speed > 8 m/s), Epsilon increased to 10^{-7} W/kg in the upper water column. Most nauplii were mixed during this event, but copepodite stages moved downward to form a distinct maximum in the turbulence minumum zone, closer to the deepening pycnocline than before. There appeared to be some hysteresis in behavior, but all stages reestablished their prior vertical distributions within a day after mixing.

SSP-23: Heterogeneity induced by vertical mixing and turbulence: Small Scale Processes

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In the coastal ocean, small scale turbulent processes are basically regarded as a great factor of homogenization. However, innovative statistical analyses, conducted on two high frequency time series of in vivo fluorescence (i.e. estimate of phytoplankton biomass), simultaneously recorded with temperature and salinity in the tidally mixed coastal waters of the Eastern English Channel and the Southern Bight of the North Sea in different tidal conditions, showed that those parameters cannot be regarded as homogeneously distributed. Indeed, the intermittent variability in time or in space of phytoplankton biomass, temperature and salinity, basically regarded as negligible, has been analyzed in the framework of universal multifractals which, contrary to basic analysis techniques as power spectral analysis, allow us to describe the whole statistics of a given field with only three basic parameters. We then demonstrated, first, that phytoplankton biomass, temperature and salinity were heterogeneously distributed whatever the scales in the framework of universal multifractals; second, that on scales smaller than 10-20 meters, phytoplankton biomass distribution was very similar to the distribution of temperature and salinity, indicating a physical control of turbulent processes; and third, that on larger scales (between 10-20 and 500 meters), phytoplankton biomass was obviously more heterogeneously distributed than temperature and salinity, suggesting a biological control over these scales.

SSP-24: Ecosystem engineering: morphology modulates chemical transport at the community scale

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"Ecosystem engineering" has recently become the focus of attention for ecologists looking at multi-species interactions. Ecosystem engineers are species that either through their activity or presence in the community affect the delivery of resources to all members of the community. In marine and aquatic communities numerous species modify the characteristics of water flow within their habitat. This modification of flow affects the delivery of resources to other members of the community by controlling rates of chemical transport between the benthos and the water column and are clear examples of "ecosystem engineering." In the research presented here, the effects of the morphology of predominant community members on rates of chemical transport are examined. Ammonium uptake by seagrass and coral communities are measured over a range of velocities using field and laboratory flumes. The relationship between uptake rate, water velocity, and morphology are compared to expected relationships based on engineering correlation of heat and mass transfer to non-biotic surfaces. Using an engineering analysis, simple morphological characteristics of the predominant species in a community can be used to predict uptake rates to within 95% of those measured in the field. These results indicate that the predominant community member can be "ecosystem engineers" and that their engineering role can be verified using engineering analysis.

SSP-25: CO_2 Fluxes from a New Jersey coastal transect: A time series approach

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A two year monthly time series was conducted across a 20 mile coastal transect to determine whether this region was a net source or sink of atmospheric CO_2. Surface waters of seven stations from the inner continental shelf, New Jersey, were sampled monthly for oxygen, TCO_2, alkalinity, nutrients, temperature and salinity. These measurements were used to calculate surface water carbon dioxide (fCO_2) and using local wind speed data, determine the yearly flux of CO_2. The transect was a small net sink for atmospheric CO_2 over the two year record. The general trends were repeatable from Year 1 to Year 2, but exhibited seasonal and spatial variability. The inner stations acted as a source of CO_2 for almost 100 days longer than the outer stations due to lower alkalinity values associated with a general freshening of the inshore waters causing higher surface fCO_2 values and a longer period of outgassing. The causes of the variability in the fCO_2 signal were estimated using ancillary data to identify the relative importance of the processes that control the fCO_2 signal. This was useful for identifying the primary processes responsible for the range in fCO_2 and demonstrates how these processes can either counteract one another or combine to produce large fCO_2 shifts.

SSP-26: Environmental Daily Variability and the Shoaling of small pelagics in the West Coast of Baja California.

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Shoaling is an amazing strategy of small pelagic fish to maximise their individual evolutionary fitness. In the productive coastal upwellings on the west coast of Baja California the small pelagics form shoals that are very important ecologically and commercially. During the past five years we have done twelve cruises studding the shoaling repertoires of sardines and anchovies using hyidroacoustic methods and trawl sampling in relation with the fine scale temporal and spatial variability of the environmental and biological conditions. Three areas were selected within the region. In each area the daily local variability was estimated covering three to four transects 10 miles apart. Each transect was monitored during 24 h in three stations: neritic, slope and oceanic, five miles apart. Between stations, surface TS and hydroacoustics surveys provide the information about the position, size, target strengh, and degree of compactness of shoals. The patterns of environmental and biological daily variability on the three zones are described together with the shoals movements and changes in compactness. It is shown that spatial and temporal heterogeneity of the ecosystem determines changes in the shoaling repertoires. The major disturbance on water masses during the 1997 ENSO event were monitored during autumn and winter. The effect of fishing on small pelagics is analyzed as an impairment of evolutionary fitness that may affect the long term population recovery after an overfishing colapse. The role of predation by sea lions, Zalophus californianus, on the shoaling of small pelagics is very relevant for the understanding of fishermen ecological interactions.

SSP-27: Evaluation of dredging effects on the pollution of sediments: The case of Mucuripe Bay, Fortalesa City (northeastern-Brazil).

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The aim of this paper is to present the effects of dredging on the sedimentary pollution in Mucuripe Bay, Northeastern Brazil, by comparison of the sedimentary contents in several pollutants before and after these dredging works (1987-1996). The oil, grease, volatile materials, organic carbon contents in sediments and their DCO show that Mucuripe Bay collects pollutants from the harbour and the town of Fortaleza. Besides it accumulates fine particles, due to its sheltered environment. The dredging works induced a redeposition of fines over a wider area then previously, and a decrease in the pollutant contents of sediments.

MEDIUM SCALE PROCESSES (MSP)

MSP-01: Seeing the North Sea by 'riding the tide'

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The development of tidal predictions epitomizes the scientific method - millennia of planetary observations inspiring Newton's theory of gravitational attraction eventually providing (following several centuries of development of computational technology) highly accurate simulations. The propagation of immense amounts of tidal energy from the oceans into shelf seas has a major determining influence on their dynamics and related ecology. The confinement of this energy within precisely defined frequency bands provides a vital reference signal to examine related phenomena via their interaction from and upon these tidal constituents. The European N.W. Shelf seas are ideally suited to this exploitation with an overwhelming predominance of the lunar semi-diurnal constituent M2. Mathematically, this predominance provides convenient first order, linear monotonic solutions for many aspects of the prevailing dynamics. These solutions then encapsulate the seemingly diverse and complex behaviour of the North Sea within a few well-ordered processes with manifestations at the mean (long term average), seasonal and 15 day spring-neap cycles in addition to those of the fundamental tidal constituents. Specific examples will demonstrate the tidal modulation of: surge and surface wave propagation, vertical stratification (saline and thermal), long-term residual circulation, sediment suspension and ambient air temperatures.

MSP-02: Cold pools and the summer circulation of northwest European shelf seas

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In summer extensive areas of the northwest European shelf become thermally stratified leaving relatively cold, dense waters (the cold pool) trapped beneath the thermocline and warmed only by the weak diffusion of heat across the thermocline. The transitions between tidally mixed and stratified water occur at tidal mixing fronts. We argue the bottom front that separated the cold pool from tidal mixed or more weakly stratified waters that is the feature of these systems that is of real dynamical significance and drives a cyclonic (dense pool to the left in the northern hemisphere) near surface flow around the margins of the cold pool (cold pool jet). Other mechanisms can form dense pools on continental

shelves such as when very saline water collects in topographic depressions and the dynamical effect is expected to be the same, namely a cyclonic surface jet around the margins of the pool. Evidence is presented which suggests that bottom fronts can be expected to remain fixed with respect to bottom topography, unlike surface fronts which exhibit considerable horizontal movement over a variety of time-scales. Bottom fronts are also likely to be baroclinically stable. The implication, which forms the basis of our hypothesis, is that the cold pool jets driven by bottom fronts will be coherent and relatively stable features. The Dooley Current in the Northern North Sea, the western Irish Sea gyre and the re-circulation of the Scottish Coastal Current in the Minch can all be explained in terms of the cold pool jet hypothesis. Importantly, however, the hypothesis predicts the existence of previously un- identified currents systems, most notably in the Celtic Sea. The possible role of cold pool jet systems for marine ecosystems, management and in the response of shelf seas to climate change are discussed. Direct observations of currents in several dense pool systems are presented in support of the hypothesis and predictions are made concerning the existence of major dense pool jet systems in regions where as yet little observational data exists.

MSP-03: Circulation and Mixing over Banks

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Submarine banks are major topographic features of many continental shelves, which can have predominant influences on hydrographic structure, circulation and mixing. Tidal and other high-frequency currents are generally amplified, and additional lower-frequency currents (e.g. seasonal gyres) can be generated over banks, with profound implications for the vertical and horizontal movement of water properties, biological organisms and suspended materials. Recent advances in understanding and modeling circulation and mixing over banks are described. Particular focus will be given to the sensitivity of drift pathways to spatial structures in the flow and to vertical position or behavior of the drifting materials. Implications for plankton retention and supply will be discussed, drawing on field and recent numerical model studies from Browns, Georges and Sable Island Banks on the NW Atlantic shelf.

MSP-04: Microplankton, organic cycling and physical processes in shelf seas

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The phytoplankton summer blooms discovered at tidal mixing fronts during the 1970s were explained by conceptual models that added simple biogeochemistry to vertical mixing physics: dissolved inorganic nutrients were converted into phytoplankton chlorophyll when and where light was sufficient for photosynthesis. Such models have proved powerful, and have been practically useful in estimating eutrophication potential in coastal waters. Yet the pelagic organisms involved in the light-driven assimilation, or subsequent remineralisation, of nutrient elements, are diverse. It now seems clear that 'characteristic' frontal blooms are due to the presence of certain types of organism which can exploit secondary circulations; and the C.E.C. (1991) definition of eutrophication, which includes 'an undesirable disturbance to the balance of organisms' requires practical notice to be taken of pelagic diversity. A general, but difficult, requirement is thus to understand the control of the balance of pelagic organisms. After this introduction to the need to deal with biological complexity in conceptual, or numerical, models of physical-biological systems, I will review modern ideas on physical forcing and plankton community structure, drawing on a recent PhD thesis by Jens Heilmann (Danish Fisheries Institute, and University of Wales, Bangor). Some of these ideas are incorporated into a numerical model, developed by Claire Smith (now at Institute of Ocean Sciences, Canada) and Karen Wild-Allen (Napier University) which contains one possible parameterisation of the biological processes involved in the cycling of the key nutrient elements, nitrogen and silicon, through the pelagic ecosystem and the benthic boundary layer. The microplankton parameterisation places phytoplankton and their protozoan and bacterial consumers within a single compartment; however, it allows there to be several such compartments in a model, and so can simulate changes in dominant organisms caused by changes in physical forcing. There are also compartments for sinking organic matter, which can be accumulated in, and resuspended from, a 'fluff' layer at the sea-bed. Depth-resolved numerical simulations have been run for a number of sites in N.W. European waters, forced by eddy diffusivities provided by a dynamically-coupled turbulence-closure model. The results will be used to demonstrate the consequences of hypotheses about key effects of (vertical) physical processes on the water-column microbiology of shelf seas.

MSP-05: Dynamics of fine sediments: observations, processes and modelling

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A major part of land ocean interaction in the coastal zone is represented by the transport of suspended particulate matter (SPM). Its mass balance is determined by the

input from rivers and adjacent seas, by advective and diffusive fluxes, and by deposition and resuspension at the sea bottom. A three dimensional Lagrangian SPM transport model will be discussed which includes all these components. It contains a current and a wave part and is driven by the actual atmospheric forcing, the tides and the baroclinic circulation. Major physical and biological processes, such as turbulent mixing, flocculation and bioturbation, are implemented by parametrisations. The model is applied to the North Sea and its coastal regions for specific periods. SPM concentrations and fluxes as well as deposition rates are calculated and compared with in situ observations and satellite images.

MSP-06: The Effect of Rivers on the Circulation in Large Estuaries and Coastal Seas

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Our current understanding of the dynamics of the circulation in the ocean has been developed by studying the response to individual forcing mechanisms. The simplifications achieved by this approach allows the development of intuition, but often at the expense of the capacity to unambiguously compare predictions to observations. This trade is particularly costly in the coastal ocean near rivers where buoyancy, wind and tidally driven motions interact with each other and with the coastal geometry. Recent theoretical developments have therefore emphasized interaction mechanisms. This paper reviews some important results in the recent physical oceanography literature. Emphasis is placed on processes that have particular relevance to biogeochemistry through their influence on vertical and horizontal transport. Remaining challenges are then illustrated by the presentation of recent observations and models of real estuaries.

MSP-O7: Influence of the Leeuwin Current on the water exchange between Shark Bay and the adjacent west Australian continental shelf

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Shark Bay is the largest semi-enclosed embayment on the Australian Coast. Like much of the Western Australian coastline, the adjacent shelf region is strongly influenced by the Leeuwin Current a warm, low salinity, poleward (north to south flowing current. The Current has a strong seasonal variance in terms of both transport and cross-shelf location. Satellite observations of surface temperature have shown that a quasi-steady intrusion of Leeuwin Current water through the major western opening to the shelf. Numerical modelling of the dynamics of this exchange process indicates that the intrusion is tidally forced, and maintained by persistent southerly winds. Consequently, significant exchange through the western opening of the Bay is likely to be restricted to periods of light, or northerly, winds and strong Leeuwin Current flow. These conditions are typical of the winter months. During summer, majority of the Bay-shelf exchange is expected to occur through the northern opening of Shark Bay.

MSP-08: Low Frequency Response of an Open Stratified Bay to Wind Forcing

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The response of the Baie des Chaleurs (BdC), a large-scale stratified bay in eastern Canada, to the passage of three storms in 1990 is discussed. Current meter, sea-level data and time-series temperature observations are analyzed and compared with output from a 3-layer numerical model. The model incorporates realistic coastal geometry and is driven by wind stress calculated from observed winds. The results show that the kinetic energy is dominated by a low frequency periods of 5-12 d, with the strongest signal at 10-12 d. This corresponds to similar variability in the synoptic wind forcing due to the rapid propagation of extratropical cyclones and the passage of pressure systems over the Gulf of St. Lawrence, including the BdC. The spectra for temperature show similar features, with the strongest signal near the density interface. The 5-12 d peak may also be related to fluctuations in the Gaspe Current, near the entrance of BdC, which are likewise correlated with wind stress at the NW of the Gulf of St.Lawrence. Furthermore, data analysis show a relationship between upwelling coastal wave propagation and alongshore wind stress in the north shore of the bay. The corresponding wave, with phase speed of 0.50 m/s, can be interpreted as a coastally trapped wave with the characteristics of a baroclinic Kelvin wave. Results from the numerical model show good agreement with observed currents in the bay during the height of the storms.

MSP-09: Coastal Phenomena Observed from Satellite Sensors: Coastal Upwelling and Coastal Currents

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Two satellite sensors used primarily for observing mesoscale deep ocean features are shown to be critical for observing coastal phenomena. The NOAA Advanced Very High Resolution Radiometer (AVHRR) used to generate global and regional sea surface temperatures for input to numerical ocean and atmospheric models is capable of detecting and characterizing coastal upwelling in areas less than 10 kilometers from the shore in shallow water depths. The resolution of the AVHRR local area coverage data is 1 kilometer, which is sufficient near the coast. Coastal upwelling off Duck, North Carolina was captured in AVHRR imagery and verified at the Federal Research Facility pier during summer 1994. TOPEX and GFO altimeter sea surface height (SSH) data are primarily used for the identification of western boundary currents and rings and to determine the three-dimensional character of the deep ocean through the relationship of SSH to dynamic height. Analysis of the original 10 Hz SSH data rather than the averaged 1 Hz (10 kilometer) data allows interpretation of the data nearer the coast. Wind-driven coastal boundary currents and coastal set-up and set-down within the coastal boundary layers of the Shantung Peninsula in the Yellow Sea and Galveston Bay in the Gulf of Mexico are extracted from the altimeter track data.

MSP-10: Sonar Studies of Shallow-Water Dynamics

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The enduring interest in coastal wave-current and wave-wave interactions, in the dispersion of contaminants there, and in the redistribution and migration of biota, bear testimony to the need for a better understanding of the mixing processes in shallow water. Upward-looking sonar offers a powerful, nonintrusive, investigative means. Scatterers observed using high-frequency, pulsed systems on the UK shelf include surface wavefronts; bubbles, generated in clouds when waves break and more uniformly during rain squalls; and planktonic and nektonic populations. The sonars have been used to measure the characteristics of the dominant components in the wave and wave-breaking spectra, and to study interactions between small and large wavenumbers. Langmuir circulation is often evident, forcing the convergence of bubbles into an array of bands. Turbulence generated tidally at the bed also affects the bubble distribution, at fairly flat, unstratified locations, of depth an order of magnitude greater than that typical of tidal creeks, where rough bed forms may force disturbance of the surface. The turbulence destabilises Langmuir circulation, and its own coherent structure may induce persistent surface separation. The observations thus allow surface and bottom forcing effects to be distinguished, and may be used to estimate the associated dispersion. In deeper water and at the shelf margins, buoyancy also affects the surface backscatter. Convergence and changes in roughness may be observed, associated with riverine fronts, and with packets of internal waves generated at the shelf break.

MSP-11: Vernal Circulation Patterns and Processes in Penobscot Bay, Gulf of Maine

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Penobscot Bay is a large geometrically complex embayment at the mouth of the Penobscot River, which is one of the most significant fresh-water point sources in the Gulf of Maine. Recent results from the Penobscot Bay Experiment, which includes the first long-term moored current measurements made in the outer Bay, suggest that the circulation of Penobscot Bay is strongly coupled with the Eastern Maine Coastal Current (EMCC) that runs southwestward along the eastern Maine shelf. Direct current measurements and satellite-derived SST patterns suggest that a portion of the EMCC enters the western side of the Bay, recirculates anticyclonically around a pair of large islands, and exits the eastern side of the Bay. Examination of wind records suggests that this anticyclonic circulation can be disrupted by strong northeasterly winds. Transport calculations based upon the direct current measurements suggest that, during the spring and summer period, the exchange between outer Penobscot Bay and the Gulf of Maine is dominated by this gyre, and not by thermohaline estuarine circulation as had been previously supposed. Patterns of larval lobster settlement within the Bay are generally consistent with the notion that, through the gyre circulation pattern, the EMCC delivers larvae preferentially to the western reaches of the Bay.

MSP-12: Continuous ferry observations in a tidal inlet between the North Sea and Wadden Sea

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Starting in March 1998 a ferry was used as a platform to obtain continuous measurements on oceanographical parameters in the Marsdiep inlet: a tidal inlet between the North Sea and the Dutch Wadden Sea. The ferry crosses the inlet with a frequency of twice per hour, daily from 06.00 to 22.00 hours so that a unique dataset is built up. From a separate water intake surface temperature, salinity and fluorescence are measured. An ADCP is attached to the bottom of the ship to record velocity and

echo-intensity profiles. In the framework of the UN-Year of the Ocean 1998 this project is used also to inform the general public of oceanographic research. Therefore (part of) the data are directly shown to the passengers on the ferry and presented on Internet. First results from these measurements will be discussed in which the focus lies on observed variations in oceanographic parameters on different spatial and temporal scales.

MSP-13: Field observations and numerical simulation of upwelling in the wake of Rottnest Island, southwestern Australia

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The redistribution of nutrients, pollution and sediments, in the wake of islands or headlands has important applications in the areas of fisheries, pollutant dispersal and sediment transport. Recent studies have documented the two and three- dimensional structure of island wakes when there is flow separation leading to a recirculating eddy. However, the wake structure when flow separation does not occur (the attached flow condition) is relatively unknown. In this study we present results of extensive field observations to show an upwelling event in the summer wake of Rottnest Island, south west of Australia. During summer, the interaction between the northward wind-driven current and Rottnest Island does not lead to flow separation but a consistent cold water patch is observed to the north of the Island. The wake structure is also numerically simulated using a three-dimensional baroclinic model. The results are shown to be in good agreement with the observations and reveal that upwelling may occur in the wake of an island even in the absence of a well-defined eddy. In addition, we show that curvature-induced secondary circulation at the tip of the island plays the dominant role in the generation of upwelling within the wake region.

MSP-14: Heterogeneity induced by vertical mixing and turbulence: Medium Scale Processes

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In the tidally mixed coastal waters of the Eastern English Channel, where mixing processes are basically regarded as a great factor of homogenisation of the water column, the medium scale variability of temperature, salinity and in vivo fluorescence (i.e. estimate of phytoplankton biomass) was investigated in the framework of universal multifractals which allow one to describe the whole statistics of a given field with only three fundamental parameters. We then showed that the medium scale variability of temperature, salinity and phytoplankton biomass can be wholly characterised as heterogeneously distributed in the matematical framework of universal multifractals, and that the similarities, as the dissimilarities, perceived between these structurations were explained on the basis of the very specific hydrological and hydrodynamical features of the Eastern English Channel. In order to specify our knowledge of these heterogeneous patterns, we subsequently focused on the structure of these parameters, together with nutrient concentration, for time scales ranging from 1 sec to 1 hr in different hydrodynamical regimes related to tidal forcing. The resultant structured heterogeneity associated with the three universal multifractal parameters then appears to be wholly dependent on the hydrodynamical conditions associated with dynamical control of the tidal cycle.

MSP-15: A model study of the wind and river-influenced circulation on the Texas-Louisiana shelf

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We are using the Princeton Ocean Model to study the three-dimensional circulation and property structures over the Louisiana-Texas shelf associated with freshwater discharges from the Mississippi and Atchafalaya Rivers and the seasonal surface winds. Work has focussed on the evolution of river plumes and fronts and their interactions to form a coastal current that flows westward along the shelf. Results show that the buoyant plume from the Mississippi spreads both east and west of the Delta, producing a bolus of freshened offshore water with a strong anticyclonic circulation embedded in its thermohaline structure. The shoreward limb of the anticyclone splits to feed the coastal current and an eastward flow back toward the Delta, consistent with observations. The coastal current continues to the west but is displaced offshore and around a front associated with the Atchafalaya outflow. Nonsummer winds aid and strengthen the westward coastal current, but during summer conditions a southwesterly wind component impedes the coastal current and spreads it seaward over the wide Texas shelf.

MSP-16: Nutrients Variability in the Upper Gulf of California during Estuarine and Antiestuarine Conditions

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The Upper Gulf of California, Mexico, is a shallow area with high nutrient concentrations all around the year. The only source of fresh water to the area is the Colorado River, which occasionally discharged large volumes into the Upper Gulf during the years when the dams were filled up. This situation occurs during 1993, when the Colorado River runoff to the Gulf of California was of 4,135 x 10^6 m3, compared with 1996 when it was null. Dissolved inorganic nutrients (PO_4, NO_3, NO_2, and SiO_2) were measured during these two years, with estuarine conditions (<33.50 salinity) during Spring 1993, and an antiestuarine situation (>36.50 salinity) during Spring 1996. Estuarine silicate concentrations reached values near 70 mM, compared with <30 mM concentrations during 1996. Phosphate and nitrate values were slightly lower during 1993. Using a biogeochemical model (LOICZ) we concluded that the area works like a nutrient importing system, mainly during the estuarine conditions. Also, the Upper Gulf of California is a net autotrophic system during estuarine and antiestuarine conditions. This area had approximately 8-fold carbon production from the ecosystem during 1993. The occasional discharges of the Colorado River into the Upper Gulf of California contribute substantially to the fertilization of the area, increasing the nutrient concentrations and the carbon production.

MSP-17: Water masses and general circulation patterns of some southern Chilean inlets between latitudes 41°31'S and 46°40'S

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A general knowledge of the distribution of water masses, degrees of mixing and circulation patterns is presented for the northern part of the Chilean inlet region. For this purpose water characteristics were registered in about 100 oceanographic stations. In general the region presents a two layer water structure as could be inferred from the temperature, salinity, dissolved oxygen and nutrients vertical distributions. Subantarctic Surface - SASW (0-150 m) and Equatorial Subsurface - ESSW (150-300 m) waters are advected into the embayments. ESSW penetrates wherever the depth of gulfs, sounds, channels and fjords allows it. SASW gets mixed with fresh water (FW) in different proportions depending from the nearness or remoteness of fresh water sources. When ESSW is no longer present the mixing of SASW and FW gets lineal. General schemes, based on water characteristics distributions, are proposed for surface (0-30 m), intermediate (30-150 m) and deep (150 m - bottom) water circulation. Two major topographic constrictions (Desertores - Apiao, < 100 m and Meninea, < 50 m) are found in the region which constrain the water circulation. Intermediate deep waters with relatively high oxygen flow over these sills and sink due to its higher density ventilating isolated basins.

MSP-18: Advances in Remote Sensing of Sea Surface Salinity

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Images of coastal and estuarine surface salinity have been produced using L-Band microwave signals remotely sensed from aircraft. An airborne swath-scanning surface salinity mapper has been flown successfully in several coastal environments along the east coast of the US. For typical sampling scenarios, salinity noise levels are a few tenths for 1 x 1 km pixels. This new remote sensing capability provides a means of substantially advancing our understanding of physical processes in the coastal zone where traditional ship-based observations are compromised due to the prevailing short temporal and spatial scales. Salinity images have been generated for the tropical waters of Florida Bay and for the temperate Chesapeake Bay under a variety of atmospheric and hydrologic forcing conditions. These data reveal local flow regimes and provide the basis for diagnostic calculation of associated low-frequency velocity fields. When combined with other data (e.g., ocean color, radar-derived surface currents, suspended sediments), details of linear and non-linear biogeophysical processes can be addressed. Analyses of tidal and sub-tidal effects will be shown. The implementation of this technology on satellites for global imaging of salinity appears feasible. Existing airborne instruments are being used as test-beds for satellite engineering studies.

MSP-19: The Energetics of Frontal Instabilities in a Buoyant Plume

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We analyzed the results of Large Eddy Simulation (LES) experiments to explore the energetics of instabilities that

develop at the head of a horizontal plume of fresh water over- riding a saltier fluid. The LES model is three-dimensional, and nonhydrostatic and has variable eddy diffusivity. The variable eddy diffusivity is a function of subgrid scale energy. This simulates the variability in downgradient diffusivity associated with variations in the dynamics at unresolved scales. In this way we parameterize only the effects of turbulence at the unresolved, subgrid, scales. The turbulence at resolved scales develops explicitly as part of the solution. Several modes of instabilities are known to exist in gravity currents. These include a rotor vortex at the head of the plume, and Kelvin-Helmholtz billows below and behind the rotor. These have been observed in the laboratory and successfully simulated in two-dimensional numerical experiments. Three-dimensional simulations of Kelvin-Helmholtz instabilities have shown a secondary instability that does not appear in the two-dimensional simulation. The instability is inherently three-dimensional and affects the restratification although it has little impact on the initial behavior of the billow. We will compare and contrast the two and three-dimensional instabilities that develop in a three-dimensional, nonhydrostatic simulation of a fresh water plume that is typical of the Chesapeake Bay outflow plume.

MSP-20: Circulation in an arctic fjord, Van Mijenfjorden

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Investigations of the circulation in an arctic fjord have been carried out based on field measurements and a 3-D numerical model (the SINTEF model). Currents, temperature, salinity and wind were observed for one week in July 1996 in Van Mijenfjorden, on the west coast of Spitsbergen. In the numerical simulations wind and fresh water runoff have been used as driving forces. The results show that the wind is the dominating driving force for circulation in the fjord, and that the circulation is strongly affected by the Coriolis force, which is also clearly reflected in the observed data.

MSP-21: Locating the position of the tip of a salt wedge in an estuary with strongly changing cross-sectional area.

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A short estuary with a cross-sectional area, A(x), and a depth, h(x), decreasing with up estuary distance, x, from the mouth is considered. A two-layer model is used to represent a salt wedge overlain by fresh water. Turbulence generated by the tide influences the vertical mixing and affects the value of the relative density difference, e=(lower layer density - upper layer density)/lower layer density. Our concern is to determine the position of the tip of the salt wedge, x`. The simple theory, based on Bernoulli and continuity equations, gives the relation Q^2/ge=h(x`)A(x`)^2. The stronger the mixing the smaller the e, resulting in moving the tip of the salt wedge downstream. Increasing the river discharge, Q, leads to the same effect. The magnitude of the displacement of the tip of the salt wedge strongly depends on the estuary geometry, h(x)A(x)^2. When its value changes slowly with x small changes in Q or e result in significant relocation of x`. This theoretical relationship was applied to the Savannah River estuary. The predicted position of the tip of the salt wedge was in good agreement with observations.

MSP-22: Interannual and interdecadal variability of sea ice cover in the Gulf of St. Lawrence in January-April

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Sea ice cover (SIC) in Jannuary-April of 1963-1996, surface air temperature (SAT) and wind in December-April of 1962-1995, and river runoff from St. Lawrence river in May of 1962-1995 were examined. The interannual and interdecadal variability were found in the fields of SIC, SAT, and eastward wind U. The largest interannual and interdecadal variability of SIC occurs in the areas off Southwestern Newfoundland. Singular value decomposition (SVD) analyses show that the most strongly coupled fields are between SIC and SAT. The correlation between the overall mean SIC over the whole Gulf and overall mean meteorological variables and river runoff suggests that the SAT plays most important role among all the forcing factors on the variability of sea ice cover in the Gulf. The wind U and river runoff also play important roles. In addition, the regression relation between SIC and SAT, wind, and river runoff was also sought.

MS-23: The physical and optical properties of the Chesapeake Bay outflow coastal buoyancy jet

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In September, 1996 and May, 1997, physical and optical properties of the fresh water outflow of Chesapeake Bay were studied with a focus on the coastal buoyancy jet which results from plume entrapment and extension along the south coast. An array of moorings with sur-

face salinity/temperature and bottom mounted ADCPs was complemented by rapid ship surveys using a flow-through system. There are two principal states which describe variations in physical and optical properties along the coast southward of the Bay entrance: a plume state and an upwelling state. When wind stress relaxes or blows toward the south, outflowing low salinity Bay water is trapped against the coast (< 10 km wide) and extends southward (> 80 km) in a high speed (70 cm/s) buoyancy jet (plume state). Wind stress easily accelerates or decelerates this jet. When wind stress is northward, the jet is rapidly replaced by coastal upwelled water and the plume is dispersed (upwelling state). Surface water exiting the Bay in the coastal buoyancy jet and upwelled water from the bottom nepheloid layer are both characterized by high optical absorption and attenuation. In this study, we present a description of the physical and optical properties in each state and examine the differences in inherent optical properties which may be extractable from optical satellites.

MSP-24: Water Balance Simulation of the Aral Sea Coastal Region

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The pressure of anthropogenic activities induced from 1961 a drastic diminution of the Aral Sea level. Intense drying-up and salinization of lands in the deltas of the rivers take place in combination with deep degradation of faunal and floral ecosytems. The desertification of this region is so pronounced that the ecological situation has gone beyond man's control. The climate has been largely modified, its continentality enhanced. Drying up of the Aral Sea and desertification of Priaral'ye is due to the wrong strategy for location of productive capacities in the sea basin, extensive water and land use, and domination of cotton and rice monocrop systems. Specific water consumption exceeds the theoretical value, due to the evident insufficiency and neglect of collector and drain networks. Hazardous pollution with pesticides and salinisation of the main sources of drinking water in the region goes on. This is combined with ample dumping of mineralized water from fields of adjacent areas into the rivers. The basic objective of this study is to quantify the water balance of one part of the coastal Aral Sea from the last decade using modelling software and the latest data available.

MSP-25: Development of Internet available information modelling system for Aral Sea coastal region

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The pressure of anthropogenic activities from 1961 implied a drastic diminution of the Aral Sea level. Resources and data are available but so disseminated that global assessment of the environmental situation is difficult. This report deals with a description of a developed information-modeling system for the ARAL sea coastal region. The general objective is to get a comprehensive review and assessment of the ecological situation. The informational-modeling system will be based on developing a specialised informational system using WWW-technology. This system must use different sources of information for studying the environmental situation and will permit receiving relevant information in real time using Internet and its tools. Now this system includes a short description of the ecological situation in the Aral region, Internet references, a soil map of the Aral region, electronic maps in vector form with some attributive information.

MSP-26: Mesoscale Subduction at the Almeria-Oran Front during OMEGA.

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During the observational phase of OMEGA, 5 repeat high resolution multi-disciplinary surveys were made of the Almeria-Oran front. This front forms at the eastern boundary of the Alboran Sea and its shape and position is variable on a timescale of days. The analysis of temperature and salinity on density surfaces has shown Mediterranean surface water advecting westwards along the Spanish coast until it reaches the Almeria-Oran front. Some of this water is entrained into the frontal jet and is drawn down along the front at a subduction rate estimated at 40-50 m/day. Horizontal current shear across the front is skewed to the north-east, the cyclonic side of the front. In the pycnocline, layer thickness changes in response to the generation of cyclonic relative vorticity. From the rapid repetition of the surveys we infer the

advection of vorticity and vertical motion. Solving the quasi-geostrophic omega equation, we have calculated vertical velocities. The diagnostic picture of mesoscale vertical motion is compared with isopycnal maps of temperature and potential vorticity, and is being used to interpret the observed correlation between biological and physical variables. The surveys show that frontogenesis processes, resulting from wave like movement of the front, cause the subduction of water along and more importantly across the front.

MSP-27: Tidal-Front Entrainment and Horizontal Transport of Fish Larvae Along the Southern Flank of Georges Bank

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The highest concentrations of cod and haddock larvae generally reside between the tidally-mixed and shelf-break fronts on the southern side of Georges Bank. Continued retention may be brought about in part by secondary on-bank circulation and active vertical positioning of larvae. In mid-May 1997, alternating between two drifters on either side of the tidal front, vertical profile sampling for larval fish and their zooplankton prey was conducted using a 1-m MOCNESS (333-um mesh nets) equipped with a high-magnification video plankton recorder (VPR), a plankton pump, and a 1/4-m MOCNESS (64-um mesh nets). Larval cod and haddock were observed to be concentrated near the tidal-front (60-m isobath) in a band 10-20 km wide. Several cross-bank CTD and ADCP sections, and satellite-tracked drifters indicated a narrow (<10 km) but significant tidal-front jet with residual along-isobath velocities of 10-20 cm/s in the upper water column (<35 m). The Dartmouth 3-D Circulation Model was initialized with observed density structure and stepped through the period of the cruise with observed winds and M2 tides. The primary focus of the model exercise was to examine potential exchange in the vicinity of the tidal front, and how it relates to retention of fish larvae on the Bank.

MSP-28: An offshore coastal bloom area: the Frisian Front in the southern North Sea

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High current velocities in East Anglian waters prevent sedimentation of the Norfolk boulder clay plume and due to the low transparency the spring bloom is absent here and nutrient levels remain high for the time of year (May/June). When these waters are transported with the residual current eastwards into the area of the Frisian Front, in between the shallow Southern Bight and the deeper Oyster Ground, tidal current velocities drop below a critical value. This gives increased sedimentation and vigorous diatom blooms, with primary production up to 8 g C/m2/d. The phytoplankton rapidly sinks out during periods of calm weather, leading to high organic carbon content of the bottom, in a SW-NE zone parallel to the contour lines at 35 m depth. In late summer, a 'green curtain', similarly SW-NE stretched, has been found frequently in the neighborhood of the enriched benthic zone. Chlorophyll can be up to 15 mg/m3 throughout the water column, versus 1-3 mg chl/m3 in adjacent waters. The extra chl is from a wide variety of diatoms, and could be caused by a substantial flux of regenerated nutrients from the bottom into the water. But the hydrography and the intensity of the bloom also suggest that the influx of nutrient-rich East Anglian water could be again involved as well. The high primary productivity by algae > 20 um makes the Frisian Front a significant nursery for organisms higher in the food chain, both pelagic and benthic.

MSP-29: Physical and Biological Processes at the Tidally Mixed Front on Georges Bank

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During 1997 the U.S. GLOBEC Northwest Atlantic/Georges Bank Program completed an intensive field study to examine processes leading to retention and loss of target planktonic species, ichthyoplankton (cod and haddock), and zooplankton (Calanus finmarchicus and Pseudocalanus), from the bank. As part of the experiment an array of current meters was placed across Great South Channel and the southern flank of Georges Bank between January and August. Also multidisciplinary cruises were completed along the southern side of the bank to examine biological processes. We discuss conditions during May near the 60 m isobath at the southwestern corner of Georges Bank. A patch of larval cod and haddock moved across the location of a bottom-mounted acoustic doppler current profiler (ADCP) during transition from vertically unstratified to stratified conditions. This vernal stratification formed a tidally mixed front at this depth on Georges Bank. Temperatures at 2 m above bottom increased from 5.9 C ±0.1 C to 7.5 C ±0.6 C during May indicating initiation of the front. From 19-22 May, a series of eight 1-m2 MOCNESS tows was made along the mooring transect on both sides of the tidal front to examine the vertical distribution of larval fish and zooplankton in relation to the temporal and spatial evolution of the front. Vertical and horizontal distributions of larval fish and zoo-

plankton were analyzed in relation to water type and currents. These results provide the first detailed concurrent physical and biological measurements needed quantify the important processes resulting in cross-frontal transfer on Georges Bank.

MSP-30: Observations of Biological and Hydrographic Interactions across the Almeria-Oran Front.

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During RRS Discovery cruise 224, five repeat fine-scale surveys were made in the region of the Almeria-Oran front as part of the observational phase of the OMEGA project. These surveys included concurrent hydrographic data from SeaSoar, biological data from the Longhurst Hardy Plankton Recorder (LHPR) and bioacoustic data from both the shipboard 150 kHz ADCP and a SIMRAD EK500 multi-frequency echosounder. Fluorescence and infrared backscatter data from SeaSoar shows that subduction occurs in the region of the front with phytoplankton being drawn down from the surface to depths of 250 m (along the 27.8 isopycnal). There is consistent evidence that acoustic backscatter is associated with this subduction. In several cases, this association persists even during periods of diel-migratory behaviour, suggesting that biological distributions are strongly affected by the hydrography in the region of the front. Distributions of LHPR bio-volumes are shown to be generally related to the backscatter from concurrent ADCP and EK500 data, with layers of backscatter broadly agreeing with variability in both biovolume and specific composition. Above 150 m the populations are dominated by copepods, chaetognaths and euphausiids, whereas below 200m the enhanced backscatter is likely to be due to myctophid fish. We are using numerical abundance and length data for particular acoustic scattering classes to model expected backscatter levels for the single-frequency (ADCP) data, and present some results. We are working towards using similar models with multi-frequency EK500 data.

MSP-31: Bottom boundary layer processes associated with fine sediment accumulation in coastal seas and bays

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Bottom-boundary-layer velocity profiles, bed stresses and suspended sediment concentration profiles were measured with instrumented tripods in five contrasting shelf and semi-enclosed bay environments that are presently accumulating fine sediments. The sites were: 1) the northern California shelf off the mouth of the Eel river; 2) the Louisiana shelf to the west of the Mississippi River mouths; 3) Eckernfoerde Bay, southern Baltic Sea; 4) the lower York River, Chesapeake Bay; and 5) the Dry Tortugas Bank, Florida Keys. Site 1) is a highly energetic open shelf regime where river sediments are deposited during flood events and frequently resuspended by moderate to high bed stresses. The other sites experience much lower bed stresses and sediments there are resuspended infrequently. Conditions at all five sites are favorable to sediment flux convergence. Typically smooth hydraulic roughness characterized all sites. In most cases, roughness elements were biogenic. High near-bottom suspended sediment concentrations, whether caused by local resuspension or horizontal advection of turbid layers, consistently increased zo, the elevation of the zero intercept of the logarithmic velocity profile. However, the effects of sediment-induced density stratification were shown to have suppressed turbulence and reduced bed stress in many of the data sets. Results suggest that relatively thick deposits of unconsolidated mud may favor further accumulation by limiting turbulent resuspension.

MSP-32: Seasonal biogeochemical particle fluxes and sediment resuspension processes in a coastal sea: The Gulf of Maine

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Results from 1995-97 deployment of time-series sediment traps in two Gulf of Maine offshore basins document strong seasonal signals in the export of particulate nutrients, opal, and $CaCO_3$. Peak fluxes occur during spring and fall, periods when phytoplankton blooms and maximum primary production rates are observed in this productive coastal sea. In terms of magnitude, POC and PON fluxes (at 150m) are similar in both basins with peak values slightly higher in the western basin. Previously, it was hypothesized that POC export would be much greater in the eastern vs. the western Gulf based on circulation patterns, nutrient distributions, timing of phytoplankton blooms, and contrasting trophodynamic systems within the two regions. Data from the present study do not support this hypothesis. Interestingly, opal and carbonate fluxes varied significantly between the regions, with the western Gulf appearing to be an opal-export system and the eastern Gulf, a carbonate-export system. Elevated lithogenic fluxes measured by traps deployed 25-35m off the bottom and transmissometer profiles document strong sediment resuspension in both regions. Tidally-driven advective input from the Bay of Fundy region is hypothesized as the primary mechanism maintaining the substantial nepheloid layer in the eastern Gulf. Extremely high levels of bottom trawling activity in the western Gulf contribute to sediment resuspen-

sion in this region, with important implications for Gulf-wide nutrient budgets.

MSP-33: Effect of tidal current rotation on the re-suspension process of sediment

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The cyclonic and anticyclonic components of the oscillatory tidal flow show a different vertical structure. The cyclonic component is characterised by a strong gradient in a relatively thin layer. In contrast, the anticyclonic component shows a more moderate shear extending over a larger distance of the water column. We think that this distinctive behaviour is of relevant importance near bottom, where entrainment of sediment occurs. Since vertical shear is responsible for the re-suspension process, this fact suggests a relation between ellipticity and some sediment features. Consequently, water masses rotating tidally in cyclonic or anticyclonic sense should have a different capacity to re-suspend sediment. This fundamental question may contribute significantly to an understanding of transport of sediments in zones where tidal currents are a dominant factor of the dynamics. To discuss this hypothesis, we use supportive evidence from recent observations (satellite imagery) and literature.

MSP-34: 3-D Visualization applied to the hydrosedimentary system of the NW Mediterranean Sea

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With the rapid evolution of computer tools, new 3-D software packages are available for the analysis of large oceanographic data sets. These packages allow the building of 3-D models merging bathymetric, sedimentological and hydrological data which can be visualized, rotated, cut, sliced and manipulated interactively. Compared to the traditional methods, such packages allow one to rapidly extract the most valuable information. Within this context, we have applied the EarthVision« software to analyse hydrosedimentogical data (temperature and turbidity) obtained in the NW Mediterranean Sea during the FLUBAL '93 cruise. Results and images presented here illustrate how the interpretation of hydrosedimentary structures can benefit from the application of these methods. The processed data show that in the northern continental margins of study area, across-margin supplies of riverine material and biogenic production are responsible for the formation of the main nepheloid structures, especially the Surface Nepheloid Layer (SNL), about 100 m thick and linked to the thermocline, and Intermediate Nepheloid Layers (INL) developed at the heads of submarine canyons. Bottom Nepheloid Layers (BNL) appear at the mouth of some canyons and at the base of the slope. In contrast, in the southern Balearic margin, the exportation of material is controlled by INL's of local extent probably associated to pycnoclines, internal waves and current over the continental slope.

MSP-35: Spatio-temporal varibility of suspended particulate matter (SPM) in a High Frequency Flux Experiment conducted in the Gulf of Lions (NW Mediterranean Sea)

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During a High Frequency Flux Experiment (project MTP II, MAST III programme) carried out in March-May 1997, a set of six daily cruises was performed in a 200 square miles area in the Eastern Gulf of Lions. One the main objectives was to study the spatio-temporal variability of the SPM distribution at a very short time scales over the outer shelf and the continental slope. SPM concentrations were determined on Nuclepore 0.45 μm filters. POC and PON contents were analyzed with a Fisons NA1500 analyzer after filtration on Whatman GF/F 0.45 μm filters. The preliminary results show that in a six week period, temporal variability of SPM concentrations, POC and PON is around 30, 20, 7% respectively, and spatial variability reaches 50, 30 and 55%. Such variability can be explained in terms of hydrological and meteorological forcings (Northern Current flow), and the North and North Western winds blowing, as well as the influence of the continental supply from the Rhone. Pico-Seston distribution (see Rodriguez-Arias et al., this conference) confirm these results.

MSP-36: Pico-Seston distribution by flow cytometric analysis during the Gulf of Lions High Frequency Flux Experiment in winter-spring 1997.

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From March to May 1997, the scientific teams working together in the MATER project (MTP II, MAST III) performed a multidisciplinary study on the Gulf of Lions shelf break and continental slope facing Marseilles. In the High Frequency Flux Experiment (H.F.F.E.) we studied the medium scale spatial and temporal variability of the sediment flux from the continental shelf to open sea in relation to the hydrographic features of the Northern Current. Our team sampled both water column suspended particulate matter (see Grout et al. poster contribution) and picoseston populations (this one). For the cytometric analysis, samples were fixed and frozen immediately. Later, at the lab, population analyses were performed in a Becton and Dickinson Facscalibur flow cytometer. We could separate the detritus from living organisms in most samples. The living fraction consisted in several populations of Synecoccocus and pikoeukaryotes and, sometimes, in a population of Prochlorophyte-like particles. The abundance of both detritus and organisms related mainly to the water mass hydrographic characteristics and the light availability, not to biological variables, neither to small scale differences. In the Gulf of Lions slope, in front of the Rhône River mouth, a coastal water mass alternated with open sea waters. These strong physical forcing determined the picosestonic composition and other biological characteristics.

MSP-37: Particle dynamics in the Southern Ocean: Results from two US-JGOFS Cruises

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Meridional sections from north of the Antarctic Polar Front Zone (APFZ) to the pack ice edge using the JGOFS CTD/transmissometer/fluorometer and a particle and optical profiling system (POPS) were made along 170W to explore particle dynamics in relationship to production and export flux in austral summer and fall aboard the R/V Revelle during December 1997 and Feb/March 1998. December results: North of the APFZ density structure was unstratified except for a thin layer of warmer surface water. South of the frontal zone the water column was stratified. At the southernmost stations the highest particle concentrations were at the pycnocline. Since nutrient concentrations were high throughout the water column at these stations this probably results from accumulation due to decreased settling velocity rather than in situ growth as in oligotrophic regimes. At the front the peaks in particle and chlorophyll concentration occurred below the pycnocline. It appears that frontal dynamics result in subduction of northward flowing water carrying a fraction of the accumulated net production of particles. As such, during periods of both stratification and high nutrient concentrations the AFPZ is likely to experience high vertical fluxes relative to the overlying productivity.

MSP-38: Indirect Analysis of Coastal Seas Pollution: Ultrasonic Volume Scattering Cross Sections of Phytoplankton

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A multidisciplinary research programme is being carried out with the objective to provide an alternative acoustical method for determining numerical abundance of phytoplanktonic algae, whose distribution in coastal seas can be correlated with polution levels. Part of this work with descriptions of the developed ultrasonic piezoelectric tranducers, at laboratory techniques for pulse-echo measurements, digital data acquisition and processing, algae species selection and culturing methodology, has already been reported1. Nowadays, efforts have been focused to analyze different formulations of mathematical scattering models as well as the influence of phytoplankton physical properties estimated values, in order to compute Volume Scattering Cross Sections for the selected algae. Previous results from other authors' theoretical studies on sound scattering by elastic shelled bodies and reported measurements analysis with copepodes have served as the basis to use Johnson model for Volume Scattering Strengths from phytoplankton with the inclusion of the effect of the cell-wall properties. Acoustical measurements are being undertaken to allow comparison between experiment and theory.

1 "Acoustical response of phytoplankton..." by S. Blanc et al. (abstract), accepted on February 1998 by Wesse\x Institute of Technology for Coastal Environment 98 Conference.

MSP-39: Physical control of phytoplankton photophysiology at mesoscale in the Gulf of Naples (Italy)

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This study aims at understanding in situ photoacclimation processes, which are the main cause of variability of primary productivity in the sea, through the study of the role of the physical structures in causing and regulating physiological adaptations. Phytoplankton distribution and photoacclimation were studied in the Gulf of Naples, in November 1995. Mesoscale sampling was aimed at studying and comparing phytoplankton distribution and photoacclimation along the water column and in the different water masses and physical structures present in the Gulf at that time. Results show different patterns of photophysiology in the different water masses and along the water column. A good relationship was found between light penetration patterns and both photoprotectant pigment (such as diatoxanthin) and the Fv/Fm ratio (measured with a PrimProd system). Phytoplankton absorption coefficients, estimated with the method of spectral reconstruction from pigments, also differ along the water column and in the different water masses. Peculiar patterns of photoacclimation parameters were observed in a frontal structure, where phytoplankton accumulated as a consequence of downward transport inside a convergent front. In another frontal structure, the photoacclimation parameters show that algae quickly adapted to lower light penetration, probably due to accumulation of suspended matter in subsurface. Our results show that the physiological adaptations of phytoplankton are strictly related to physical structures, and that photoacclimation parameters can be used to track the relative movements of water masses.

MSP-40: Physical structures and phytoplankton: a combined study of HPLC and flow cytometry

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This study tries to assess the influence of water mass characteristics and of physical structures over phytoplankton variability in distribution and production. HPLC and flow cytometry are used to estimate the relative contribution of different algal groups to the total biomass. Marker pigments allow one to estimate the proportion of different algal groups, and also to calculate Fp, a ratio indicating the ratio of "New" Production over Total Production. Flow cytometry is used to count ultraphytoplankton, and to gather informations on their adaptive strategies. The sampling strategy aimed at characterizing the different water masses present in the Gulf of Naples: coastal, offshore, MAW (Modified Atlantic Water), as well as the physical structures such as a gyre and several fronts. The phytoplankton communities depend on the physical and trophic characteristics of the water masses. The MAW, always present below 40 m, presents its own phytoplankton community, with Prochlorophytes exhibiting a bimodal distribution of size and chlorophyll fluorescence. This reflects the existence of two populations replacing each other along the water column, most probably as a response to changing nutrients and/or light conditions. Fp is higher in the coastal area, low offshore and intermediate in the MAW, reflecting the relative proportions of diatoms and dinoflagellates, main contributors to the "New" production. This study shows that HPLC and flow cytometry together are very useful to study heterogeneity of phytoplankton at mesoscale.

MSP-41: Real-time visualization of taxa-specific plankton distributions

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A fundamental problem in plankton ecology has been the inability to measure species distributions quickly over a broad range of scales. Traditional sampling with bottles and nets provides limited spatial and temporal coverage and requires extensive analytical effort. We describe results from a recent field study in which a new computerized video sampling system was used to automatically identify planktonic taxa and visualize their distributions in real time. Representative data for phytoplankton and zooplankton taxa reveal the ephemeral nature of plankton abundance patterns and demonstrate the utility of this approach for quantifying processes controlling plankton distributions in dynamical fluid environments.

MSP-42: The summer subsurface production engine of the North Sea: causes and consequences

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Observations during summer months in the North Sea, consistently show subsurface chlorophyll peaks within the seasonal pycnocline. These peaks and associated primary and secondary production are particularly pronounced adjacent to shoals such as the Dogger Bank (Nielsen et al 1993, Richardson et al 1998). We report observations of a persistent elevated oxygen layer associated with this peak north of the Dogger Bank. We argue that this oxygen is associated with new production of 4 to 7 gCm-2 averaged over an areal extent cov-

ering 100 km off the Dogger Bank. This can be compared to an estimated new annual production averaged over the whole North Sea of about 40 gCm-2 (Richardson and Pedersen 1998). We examine physical processes which can maintain production in the face of nutrient limitation and stratification. The mechanism most consistent with observations appears to be the so called "tidal pump" (Pedersen 1995). This is associated with the fortnightly advance of tidal mixing down the flanks of Dogger Bank producing water of intermediate density and high in nutrients which spread laterally, interleaving the pycnocline and stimulating new production. While demonstration of this mechanism is preliminary, it is clear that an important process is in action, powering primary production of the North Sea, and maintaining secondary production throughout the summer.

MSP-43: Factors influencing on the seawater light extinction coefficient in two Mediterranean bay systems

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The relationship between the light vertical extinction coefficient, suspended matter concentration (i.e.: of total dry residue, total volatile and fixed residue, and chlorophyll a) and turbidity is analysed for two bay systems of the Mediterranean island of Mallorca. It was observed that light regime is not closely correlated with any of the factors analysed. The correlation coefficients (r) obtained oscillated from 0.10 to 0.81. The results reflect a great spatial heterogeneity of some environmental factors, as well as the importance of synergism in ecological processes. When both bays are compared, the bay which is more open to the sea has lower r values (mean: 0.43), although they are less dispersed (0.37-0.49), as well as a greater effect of chlorophyll on light extinction. On the other hand, in the other bay correlation coefficients are higher (mean: 0.60), although their range is much higher, and the extinction appears to be more associated to the total quantity of solids in suspension. These results are interpreted as being a function of the different incidence of epicontinental systems on the sea coast, and particularly of the importance of anthropogenic activities, which in both cases result in an increment in suspended mineral matter concentration, while phytoplankton growth is sometimes also favoured.

MSP-44: Variations in Specific Absorption Coefficients and Total Phytoplankton in the Gulf of California

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From 15 to 19 October, 1994, an oceanographic cruise was carried out in the Gulf of California. Phytoplankton biovolume, pigment concentrations and taxonomy were examined as functions of location and light depth. The phytoplankton specific absorption coefficient (a*ph) showed variability in magnitude and spectral shapes between stations and with depth. The a*ph values ranged throughout the stations from 0.020-0.056 m2 (mg Chla)-1 at 440 nm and 0.013-0.020 m2(mg Chla)-1. Spectra of phytoplankton belonging to the same taxonomic group tended to have similar shape. Stations where the environmental conditions favour the development of microphytoplankton populations (cells>20 um),presented the lowest a*ph. Of all the variables studied, pigments and, in particular the photoprotective pigment zeaxanthin had the highest correlation with a*ph. Changes in pigments composition and cellular concentration were responsible for over 70% of the variability of the specific absorption at 440 nm. Including biovolume per cell in a multiple regression improved the model to explain up to 80% of a*ph variations. The work described here concurrently examined pigment packaging, measured as the cellular concentration of cholorophyll a and as the phytoplankton cell volume, and the confounding effect of the blue-absorbing accesory pigments on the specific absorption coefficient. The a*ph varied as a function of all 3 variables indicating the importance of both taxonomic variations (size and accesory pigments) as well as responses to environmental variations.

MSP-45: Spatial Patterns of Plankter Transport and Dispersion in a Louisiana Coastal Bay

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The U.S. Louisiana coastline is a series of barrier islands separating large inshore embayments from Gulf of Mexico waters. Estuarine dependence is a common life history in this region, where residence of early life history stages in coastal bays either precedes or follows an offshore, neritic phase. Ingress through tidal passes is a critical component of the life history, but must then also be followed by retention in, and dispersal through, the coastal bays. Field studies of within-estuary transport were conducted in Barataria Bay, Louisiana. Drogue

tracking was conducted during the summers of 1994 through 1996. A total of 22 tracking sessions lasting up to a full tidal cycle were completed using clusters of 4 to 9 drogues per track. Individual drogue positions were determined approximately every thirty minutes using a GPS receiver with differential correction. The analytical methodology of Okubo and coworkers was used to compute Lagrangian deformations and turbulent diffusivities from the drogue positions. Graphical results from these analyses will be presented and interpreted with respect to probabilities of successful retention, transport, and settlement of blue crab (Callinectes sapidus) megalopae within the bay.

MSP-46: Relationship between water temperature and recent growth of larval cod and haddock

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In May 1992, 1993 and 1994, we studied growth and mortality of larval Atlantic cod (Gadus morhua) and haddock (Melanogrammus aeglefinus) on the southern Flank of Georges Bank. Each cruise began with a grid of bongo net tows to identify concentrations of larvae, followed by a series of depth-discrete 1- and 0.25-m2 MOCNESS tows to sample larvae and their prey, and monitor environmental conditions. Most larvae in all three years appeared to be in good condition and growing rapidly. Mean growth coefficients, estimated from water temperature and larval RNA/DNA ratio, were 0.11/d for cod and haddock. Slower growing larvae were found in colder water to the northeast and in warmer water to the southwest in an area of slope-water intrusion. Larval growth was highest in 1993 when water temperature was intermediate between cooler 1992 and warmer 1994 temperatures. A dome shaped relationship was observed between recent larval growth and water temperature. Maximum larval growth corresponded to a water temperature of about 7 degrees C. The factors contributing to the observed variability in larval growth are under investigation.

MSP-47: Diurnal signals in vertical motions on the Hebridean shelf

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We consider the interpretation of measurements of vertical velocity and backscatteredintensity, made using a Doppler Acoustic Current Profiler mounted on the sea bed on the Hebridean Continental Shelf. The existance of vertically migrating scattering agents is inferred from both the intensity and vertical velocity data, which indicate migration rates of 2 - 3 cm/s. Close phase locking between the motion and day light times, and vertical displacements close to the water depth, have led us to interpret the signal in terms of the vertical migration of zooplankton scatterers. The 12 days of data available show an initial period during which there is a strong vertical migration signal, and a later period during which the signal not clear. The change in character of the signal is discussed in terms of possible mechanisms to changes in the light environment and to horizontal advection.

MSP-48: Acoustic surveys of zooplankton, internal waves, and suspended sediment over the Georges Bank region and interpretations using acoustic scattering models

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A series of acoustic surveys have been conducted recently over the Georges Bank (an area near Cape Cod, Massachusetts, USA). The surveys reveal that on top of the bank within the 60 m isobath, zooplankton and suspended sediments contribute significantly to the volume backscattering. In deeper waters of the Bank out to the continental shelf break, internal waves are often present and may contribute to the volume backscattering independently from the zooplankton. Concurrent with the acoustic measurements were net tows, tows of a video plankton recorder (VPR), and surveys of physical properties of the water. The data are combined with acoustic scattering models of the various objects or phenomena present in order to identify the degree to which each contributed to the scattering. Methodologies are presented with regard to use of acoustic systems for quantitative surveys of regions where a variety of types of sound scatterers, such as zooplankton, suspended sediment, and internal waves, are present.

MSP-49: Retention and ingestion of protists by the oyster Crassostrea gigas: protists as a trophic link between picoplankton and benthic suspension-feeders

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The oyster Crassostrea gigas obtains energy resources by filtering microalgae (5 to 100 μm). However, in turbid estuaries, light-limited phytoplanktonic production cannot entirely account for oyster energy requirements. Conversely, picoplankters (< 2 μm), which are main effectors of coastal energy flow and matter cycling, are not efficiently retained by oyster filtration. Protists, as both micro-sized cells (4 to 100 μm) and bacteria/-cyanobacteria grazers, may represent a major intermediary in trophic transfer between picoplankton and filter-feeding metazoa. The ciliate Uronema was isolated from an oyster rearing pond of the atlantic coast (Charente) cultured and labelled, using the cyanobacteria Synechococcus as an autofluorescent biomarker. Labelled ciliates were offered as potential prey to the oyster. Likewise, a natural community of protists from the oyster pond was offered as prey to the oyster. We observed 90% retention of protists (ciliates and flagellates) and a significant ingestion of labelled ciliates by oysters, supporting the role of protists as a realistic trophic link between picoplankters and filter-feeding bivalves and thus enhancing their potential importance in coastal microbial food webs.

MSP-50: Transport of Pectinaria koreni larvae in the Bay of Seine (English Channel): a modeling study of the roles of tidal advection and wind-driven currents

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The drift of Pectinaria koreni larvae in the eastern Bay of Seine have been investigated using a 2D numerical model which integrates residual tidal currents, wind-driven currents and diffusion. Larvae are considered as inert particles with a planktonic phase lasting 15 days. Drifters starting positions correspond to major adult aggregations located off the Seine estuary. The model shows that most larvae are transported to the west and the north-west of the bay by tidal currents alone and just 1.39 % of released larvae reach the adult habitat. However, simulations revealed that wind-induced currents have a determinant effect on the dispersal patterns, which sometimes strengthens or sometimes is opposed to the tidal effect. The proportion of larvae retained near the adult population varies between 0.15 and 2 % under the most frequent wind conditions. The model results obtained for two larval cohorts transported under real tidal and wind conditions in 1987 matched the observed data remarkably well. Despite high advective losses, no significant exchange of larvae with neighbouring populations occurs so that the Pectinaria koreni population of the Bay of Seine should be considered self-sustaining.

MSP-51: Tidal interaction with a sill in Ragay Gulf, Philippines

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The presence of a topographic sill across the mouth of Ragay Gulf, Philippines which separates the gulf from the open ocean at depths below 150 meters produces a two-layer hydrographic structure as observed from Conductivity Temperature and Depth (CTD) profiles. Water column properties in the interior and exterior of the gulf were found to be almost similar in characteristics in the upper 150 meters where the temperature and salinity exhibited strong seasonal variability as influenced by meteorological forcings. However, below this depth, the properties inside the Gulf were nearly constant with depth and are very close to the values observed at 150 meters outside the gulf. This depth coincides with the depth of the topographic sill at the mouth. It is hypothesized that the source of the lower gulf waters must be through sill overflow, and this is maintained by energy produced from internal waves generated at the sill. In the present study, a three-dimensional coastal ocean numerical model (Princeton Ocean Model) was used to simulate the generation of internal waves responsible for driving the vertical mixing in the gulf. Varying degrees of stratification outside the sill was used to determine its influence on the evolution of the thermocline structure in the interior of the gulf. Results are geared toward estimating the ventilation rates of the gulf's bottom layer water.

MSP-52: Evolution of borelike internal waves observed near the shelf break in the East China Sea

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Boundary mixing in the margin of the ocean may be a quite important process to understand transportation of materials from continental shelf to open sea as well as to evaluate energy dissipation of the ocean circulation. The boundary mixing may take place through deformation of internal waves with short time scale. To examine the evolution of internal waves generated around shelf break, short term current measurements were carried out near the shelf break in the East China Sea in November 1997. Two arrays with three current meters each were moored with a short distance, around 200m, between two arrays. Water depth at the mooring site is about 213m. And the current meters of each array were placed around the thermocline at 50, 70 and 90 m above the sea floor, respectively. The period of the measurement was just a few days with a short sampling inter-

val, one minute. Borelike internal waves which propagate onshelfward were sometimes observed. After the occurrence of the phenomena, internal waves with shorter time scale followed for several hours. Temporal variation of temperature obtained at the three levels shows that borelike internal waves tend to be generated corresponding to the tidal phase and the vertical stratification was significantly weakened after the passage of the borelike internal waves.

MSP-53: Processes of Vertical Exchange in Shelf Seas (PROVESS)

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Vertical exchanges are principally controlled by the water column's turbulence characteristics. Turbulence is generated at the surface, by wind and waves, and at the bed, by friction. At the pycnocline turbulence levels are reduced and vertical fluxes can be inhibited. Turbulence characteristics therefore depend on and affect the water column's thermodynamics and dynamics and their interaction with the sea bed and surface. Considerable reliance is placed on turbulence closure schemes to quantify fluxes in shelf sea environmental models. The current failure to estimate the entrainment of nutrients into the photic zone stems from an inability to quantify vertical fluxes across the thermocline and to determine which processes control nutrient recycling in the benthic boundary layer. PROVESS will study the physical-biological coupling involved in recycling. A key will be to distinguish processes in the water column from those in the 'fluff layer' formed by freshly deposited particulates, from those in the compacted sediment. Measurements of turbulence dissipation rate throughout the water column and intensity over a wide frequency range, and of fluxes near the sea bed, will be made at two contrasting North sea sites - one shallow, high energy; the other deeper, low energy. Since turbulence directly affects the environment perceived by particles, including biota, detritus and suspended sediment, studies will be made of aggregation and of trophic interactions. This international project, 1998 - 2001, will contribute to the development of robust water column plankton shelf sea models tested over a range of turbulence environments.

MSP-54: The Vertical Structure of Mixing on the Southern Flank of Georges Bank

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Microstructure and acoustic Doppler current profiler (ADCP) measurements were made at two sites on Georges Bank: in a shallow (45 m) well-mixed region on top of the bank and in a deeper (75 m) more stratified region on the southern flank. Each site was visited twice, April 25 to May 3, 1995 and June 6 to 16, 1995. At both sites the dominant variability in the turbulent kinetic energy dissipation rate was related to the semi-diurnal M2 tide. In the well-mixed, lower portions of the water column, a phase delay between the dissipation rate and current speed, increasing with height above the bottom, was observed. Analysis of the vertical structure of the M2 tidal velocity shows a similar phase lag between tidal velocity and vertical shear. A simple, one-dimensional eddy viscosity model is used to interpret the observed velocity and microstructure data at these sites. Using data assimilation, the model dependence on the vertical structure of the eddy viscosity, pressure gradient and bottom drag coefficient are explored.

MSP-55: 3-D Water Quality Modelling for Korean Coastal Waters in the Yellow Sea

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Increasing loads of nutrients and contaminants from river discharge, non-point surface flows and the air draw out increasing attention on coastal water quality control in the Yellow Sea. The hydrodynamics of the coastal waters is evidently three dimensional with very complicated mixing-advection processes in nature. Moreover, the long-term monitoring of water quality shows significant variablity in horizontal and vertical spaces and in time. This study demonstrates a three-dimensional water quality model for diagnostic and prognostic applications to coastal waters in the Yellow Sea off mid-west coast of Korea. The water quality model consists of 3-D hydrodynamic models of generic POM's, and 3-D eutrophication model developed for the Chesapeake Bay Program. The hydrodynamic model is verified with observed vertical structures of coastal current measured by ADP's (NORTEK/SONTEK) and with fine structures of water quality parameters. The study area covers the big estuarine waters where major river discharges from South Korea and North Korea merge together.

MSP-56: On the Use of Laboratory Observations to Validate Numerical Models

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In order to develop data sets which can be used as benchmarks for coastal circulation numerical models, laboratory experiments are conducted in a cylindrical tank in which a continuous continental shelf model, interrupted only by a single smooth canyon, is placed along the periphery of the test cell. Prior to experimentation, the tank is filled with a linearly stratified fluid and the tank is then slowly brought up to solid body rotation with Coriolis parameter f. To initiate the experiments, the turntable rotation rate is then either (i) modulated sinusoidally about the background rotation rate f/2, or (ii) impulsively charged by . These changes in the rotation rate drive an along-shore current which is either (i) oscillatory or (ii) steady. The objectives of the experiments are to (i) observe and better understand the motion field in the vicinity of a submarine canyon and (ii) provide horizontal maps of the horizontal velocity, vertical vorticity and horizontal divergence fields using particle tracking techniques. Observations at numerous vertical locations, including those above and blow the canyon rim, are presented. Special attention is given to the mean currents driven by this physical system. Comparisons are made between the laboratory results and a numerical model (SPEM) for the steady flow case.

MSP-57: NCOM Coastal Ocean Model

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A three-dimensional, baroclinic, ocean model has been developed for application to coastal regions. The model has a free surface and is based on the primitive equations and the hydrostatic, Boussinesq, and incompressible approximations. The model uses an Arakawa C grid, is leapfrog in time with an Asselin filter to supress timesplitting, and uses second-order, centered spacial finite differences. The propagation of surface waves and vertical diffusion are treated implicitly. A choice of the Mellor-Yamada Level 2 or Level 2.5 turbulence models is provided for the parameterization of vertical mixing. The horizontal grid is curvilinear. The vertical grid uses sigma coordinates for the upper layers and z-level (constant depth) coordinates for the lower layers, and the depth at which the model changes from sigma to z-level coordinates can be specified by the user. The combined vertical coordinate system provides some flexibility in setting up the vertical grid, and easily allows comparisons to be made between simulations conducted with sigma and z-level coordinates. The inclusion of a source term in the model equations simplifies input of river and runoff inflows. The model structure makes it easy to couple with submodels, e.g., biological and optical models. A description of the model and results from some simulations will be presented.

MSP-58: Modeling Tide in the Gulf of Maine

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The Gulf of Maine and Bay of Fundy system is well known for its nearly resonant response to M2 tide. The Princeton Ocean Model is used to study the tide and associated tidal rectification. The model has an orthogonal curvilinear grid in the horizontal with variable spacing from 3 km nearshore to 7 km offshore, and 22 levels in the vertical with fine resolution in the surface and bottom boundary layer. The modeled M2 tide compares favorably with that in the tidal atlas of Moody et al. (1984) at most stations in the Gulf of Maine. Sensitivity of the modeled M2 tide to open boundary forcing, tidal barrier in the upper Bay of Fundy, bottom boundary layer, and bottom drag coefficient is also examined. Other major tidal constituents (S2, N2, K1, and O1) are also computed. Tidal rectification has limited influence on the annual evolution of the gulf-wide, sub-tidal circulation. However, it plays the leading role in establishing the anticyclonic circulation over Georges Bank.

GOOS

GOOS-01: The Implementation of the Global Ocean Observing System (GOOS)

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GOOS is designed to: (i) provide reliable assessments and predictions of the present and future state of seas and oceans, to support their efficient, safe and sustainable use; and (ii) contribute to predicting climate change for the benefit of a wide variety of users. It is an oceanographic analog of the WMO's World Weather Watch, which underpins the gathering of meteorological data and weather forecasting worldwide. It will be built on the success of research programmes like TOGA, WOCE, JGOFS, LOICZ, GLOBEC and CLIVAR, which help to understand how the oceans work. It will rely on systematic, long term observations made in situ, and by remote sensing from satellites. Implementation is incremental, and has begun. The GOOS-Initial Observing System is based on existing observing systems, and includes: the TAO array of buoys in the equatorial Pacific; the Ship of Opportunity (SOOP) network; the WMO's Voluntary Observing Ship (VOS) network and Global Telecommunications System (GTS); the Global Temperature Salinity Profile Programme (GTSPP); the Global Sealevel Observing System (GLOSS); and the buoys coordinated by the Data Buoy Cooperation Panel (DBCP). GOOS concepts are being tested through Pilot Projects (currently NEAR-GOOS in N.E.Asia, and EuroGOOS in Europe), and through demonstrator projects like GODAE, the Global Ocean Data Assimilation Experiment. The initial focus is on physical oceanography and the open ocean. Next we will add the coastal dimension, including living marine resources and pollution.

GOOS-02: Coastal GOOS: What It Is and Why Do It?

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In the context of increasing pressure from human activities on coastal systems, the coastal component of the global ocean observing system (C-GOOS) is intended to promote activities that will overcome impediments to predicting environmental changes, trends and consequences in coastal systems, and assist in the sustainable development of these environments. In addition to local-regional expressions of global climate change, C-GOOS encompasses globally ubiquitous, local-regional scale effects of human activities on ecosystem services. C-GOOS addresses the causes and consequences of environmental change, and the efficacy of coastal management policies and actions in terms of the sustainability of healthy coasts, the mitigation of natural hazards, and safe navigation. The ultimate goal of C-GOOS is to promote the development and application of predictive coastal models, so as (i) to improve the scientific understanding of coastal ecosystems and (ii) to improve the human condition through reliable forecasts of the effects of climate change and anthropogenic alterations of coastal ecosystems. Achieving this goal requires the implementation of regional-global networks that link observation, analysis, and user needs in effective and timely ways. Thus, C-GOOS is formulating a strategy to promote (1) increased public awareness of the interactive effects of climate change and human activities in the coastal zone; (2) the use of remote and in situ sensing technologies and real-time data acquisition, assimilation and analysis; (3) more timely exchange of information and knowledge among scientists working in the coastal zone; and (4) more effective linkages between environmental science and user groups outside the scientific community.

GOOS-03: A Pilot Research Moored Array in the Tropical Atlantic (PIRATA)

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Monitoring the tropical oceans is critical to understanding short term climate variability in these sensitive environments. The Tropical Atmosphere Ocean array (TAO) of buoys in the equatorial Pacific, emplaced during the TOGA experiment, has improved skill in forecasting El Niño events. The tropical Atlantic Ocean also has a large seasonal cycle around which there are climatically significant inter-annual and decadal variations including: (i) warm events rather like the El Niño events of the Pacific, and (ii) the so-called Atlantic sea surface temperature (SST) dipole. Both phenomena may be related to El Niño/Southern Oscillation (ENSO) variability in the tropical Pacific and other modes of regional climatic variability in ways that are not yet fully understood. PIRATA (Pilot Research Moored Array in the Tropical Atlantic) is designed to remedy the lack of oceanic and atmospheric data which limits our understanding of the equatorial Atlantic and its climate. The PIRATA array comprises 12 moored ATLAS buoys to be deployed between 1997 to 2000 to monitor surface variables and upper ocean thermal structure at key locations. Seen as a pilot GOOS/GCOS experiment, PIRATA will contribute to real-time monitoring of the tropical Atlantic, and may well lead to an operational monitoring system after year 2000. There are plans to deploy similar buoys in the tropical Indian Ocean, to complete equatorial coverage of data sparse areas by observing systems.

GOOS-04: Blue Water GOOS and the Global Ocean Data Assimilation Experiment

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Planning for the blue water component of the Global Ocean Observing System began almost a decade ago. Based on experience with climate research programs like TOGA, and the planning of WOCE, it was realised that oceanography must eventually come to terms with non-research modes of operation. This paper will discuss some of the milestones, and setbacks, of the last decade and show that, at last, we are on the brink of turning the concept into reality. In part this is being achieved by taking what were dis-integrated and, in some cases, unsystematic measurement networks and transforming them into systematic, integrated and long-term elements of a blue water global ocean observing system. The supporting structures are being renovated to make blue water oceanographic measurements a central, shared mission. The other strategy is centred on an international initiative called the Global Ocean Data Assimilation Experiment. The objective of GODAE is to demonstrate the practicality and feasibility of routine, real-time global ocean data assimilation and prediction, in effect a "proof of concept" for GOOS. Drawing in part on the experience of meteorology and its FGGE, GODAE is aiming to peak through the period 2003-2005 when observing systems and modelling capabilities will be at their height. This paper will discuss the present status of GODAE and outline the strategy for meeting the challenges which lay ahead.

GOOS-05: GOOS and Living Marine Resources

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The Living Marine Resources Panel of GOOS met in Paris in March 1998 to forward the planning of this GOOS module. To be useful the plans for this module must be widely adoptable. The design challenge is thus to create a blueprint: - that appropriately addresses the different spatial and temporal scales of the pyramid of life in the oceans; that is universal in scope; that can be developed with low level technologies, but can integrate new technologies where these are available, and can incorporate emerging methodologies as these become operational; that gives the maximum scope for all educative exchanges; that addresses both the practical, and short term needs of the countries conducting the work, and the longer term global endeavours of the GOOS community; and that is firmly linked to modelling and hypothesis testing. Proposals to achieve this include, inter alia, studies and modelling of: - the changing size spectrum of living particles in the various regions of the oceans and shelf seas; biodiversity stability and change; spatial/temporal processes of N, P, Z levels; the spatial and/or temporal integration of fish and other top predators with the primary and secondary producers, particularly as it affect fish recruitment processes; the response of marine ecosystems, especially their higher trophic levels, to environmental forcing at different climate scales. The challenge is to implement these to meet a wide spectrum of user needs in the GOOS context.

GOOS-06: Launching the European Global Ocean Observing System (EUROGOOS): The First Three Years

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EuroGOOS is an association of 30 national agencies from 15 European countries. Formed in 1994, it is dedicated to operational oceanography in Europe, combined with real time modelling and forecasting for economic, social, and environmental purposes. The scales of activity include systems to support services in regional seas such as the Baltic or Mediterranean, at the pan-European scale, and the implementation of European participation in GOOS at the global scale. The first actions were to identify, and where possible deliver, the products which are needed in each regional sea area. This requires working collaboration between operational agencies from the countries bordering each sea. EuroGOOS Members are, in general, running models and providing forecasts of physical parameters such as sea level, storm surges, temperature, salinity, floating ice, winds, wave spectrum, and currents. Some agencies are providing real time or near real time data on chlorophyll, suspended sediments, plankton blooms, and the movement of oil slicks. Priorities are: expanding models and services in the Mediterranean and Atlantic; developing labour-saving technologies to provide higher resolution data and greater geographical coverage; developing and testing new operational models; investigating the scientific and practical limits to predictability; improving real time operational data exchange and data quality standards; and developing consistent economic methodologies for evaluating the costs and benefits of operational oceanography on European and global space scales, and all time scales from daily to decadal.

REGIONAL SCALE PROCESSES (RSP)

RSP-01: A Quarter Century of Progress in Coastal Upwelling Research

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By the early 1980s coastal upwelling research was a well-defined subdiscipline with a powerful theoretical basis and a thorough observational foundation for a select few coastal upwelling regions. During the last two decades this subdiscipline has continued to mature and, in particular, the important air/sea and water/sediment sequelae of coastal upwelling have been investigated. This review will summarize the progress and describe how our 1980s view of coastal upwelling has changed.

RSP-02: The Benguela Current system: Circulation and Productivity

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The Benguela System can be divided into three subsystems, each with two main upwelling cells. Upwelling appears to occur in two stages: in stage one, water upwells onto the shelf from over the slope at three topographically defined "gateways", and is enriched in nutrients as it moves polewards over the shelf before stage two, when it is wind-lifted into the photic zone at one of the main upwelling cells. It then drifts equatorwards near the surface and is stripped of nutrients by phytoplankton blooms. Diatoms bloom some 4-8 days after an upwelling event commences, and studies have shown that small diatoms (such as Chaetoceros sp.) provide good food for copepods, resulting in rapid egg production 3-4 days after upwelling, in immediate response to diatom production. Net- phytoplankton (>20μm) take up more nitrate than smaller phytoplankton cells, leading to a biomass increase after upwelling, and a five-fold increase in the flows of carbon to mesozooplankton compared to the periods between pulses of upwelling when the microbial loop sustains the mesozooplankton-fish foodweb at a low level. The microbial loop is slightly stimulated by upwelling. The pulsed upwelling of the southern Benguela subsystem results in a mismatch between the time scales of the microbial foodweb (1-2 days), diatom blooms (4-8 days), mesozooplankton (12-30 days), and anchovy (1 year). The Central Benguela subsystem has strong perennial upwelling and accounts for a good deal of the potential production of the whole system. The cool water and deep mixing appear to act as a barrier separating the northern and southern stocks of small pelagic fish. The Northern Benguela subsystem has gentler and relatively continuous upwelling which results in sustained diatom blooms and high phytoplankton biomasses. Here it appears that there is a better match between phytoplankton, zooplankton and fish in a short food web. This subsystem is periodically disrupted by intrusions of warm, nutrient-poor water from the north (Benguela Ninos) and by intrusions of oligoxic water along the shelf on similar time scales.

RSP-03: Processes Affecting the Fate of Amazon Discharge

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The Amazon River supplies about 10% of dissolved and particulate loads supplied to the global ocean by rivers and is representative of the geographic category known as wet tropical rivers, which collectively provide over 50% of the total fluvial flux. However, processes operating near the mouth of the Amazon River control the escape, transformation, and entrapment of material. A range of energetic oceanographic processes are active on the Amazon shelf: large freshwater discharge, strong tidal currents, nearly continuous trade winds, and the North Brazil Current. The interactions of these processes cause landward bottom currents, turbid surface waters, and northwestward transport of shelf water, which impact the fate of river materials. The bottom currents trap particulates on the shelf. Turbid water limits primary productivity and uptake of nutrients. The northwestward flow leads to a dominant along-shelf dispersal for materials carried beyond the river-mouth region. Budgets of dissolved and particulate components document the impacts of ambient processes on the fate of materials. For example, 94% of the riverborne dissolved silicon ultimately escapes the shelf, with 33% of the flux in the form of particulate biogenic silica. About 50% of the inorganic sediment accumulates on the shelf near the river mouth (within 500 km) and about 10% escapes to more distant coasts of northern South America. The remainder of sediment may be trapped in lower reaches of the river. Observations of other diverse materials demonstrate that operative mechanisms have variable efficiencies for allowing escape to the regional and global ocean.

RSP-04: Simulation of recent changes in the functioning of ecosystem and the upper layer biochemical structure of the Black Sea

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The processes governing the biogeochemical structure of the upper layer water column in the central Black Sea are studied using a coupled physical-biogeochemical model. The model investigates the role of several factors which led to drastic changes in functioning of the ecosystem within the last three decades in the Black Sea. The simulations reproduce reasonably well the observed, present-day annual plankton structure involving a series of successive phytoplankton and zooplankton peaks over the year. It is shown that these peaks become progressively stronger since the 1970's as a result of increased anthropogenic nutrient load from the major rivers. As a result of recent increased population of gelatinous carnivores in the system, the yearly phytoplankton distribution is shown to possess more pronounced summer bloom structures due to stronger "top-down" control by these gelatinous carnivores. The position of the nitrate maximum appears to be intimately related with the location of the onset of trace level oxygen concentrations as they control the lower limit of the nitrification and the onset of the denitrification in the water column. The model successfully simulates the observed seasonal and vertical variations of the dissolved oxygen in response to its atmospheric and photosythetic productions, and losses during the particulate matter decomposition and nitrogen transformations.

RSP-05: The Barents Sea: Interdecadal variability in ecosystem energetics and productivity

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The Barents Sea is divided into a southwestern Atlantic Water domain and a northern Polar Water domain by the oceanic Polar Front, at about 74°N. The Atlantic domain is characterized by ice-free waters and a primary productivity of about 170 g C m-2 yr-1, whereas the Polar domain is about half as productive, or in cold years, considerably less as a result of the variable ice cover and shallow mixing of the water columnm (20-30 m). In the Atlantic domain, lower stability and mixing to 40-80 m depth, caused by the westerlies, supply annually as much nutrients as the winter mixing. The pelagic ecosystem in the Barents Sea is not in an "ecologically balanced" state. Major interdecadal changes may be related to the transport of heat with the Atlantic Current and, thus, the North Atlantic Oscillation. Predominant cycles are 3-5, 11 and 18.5 years. Warm years (little sea ice) are successful years for plankton and capelin and ultimately lead to large cohorts of cod, seals, seabirds, and whales. Conversely, the transition from a warm to a cold period may imply fish stock collapse and, ultimately, mass mortality of seals and capelin-feeding seabirds (e.g. 1901, 1989). "Aftershocks" of such transitions may reverberate through the ecosystem for about three years.

RSP-06: The Hydrographic Milieu of the U.S. JGOFS Arabian Sea Process Experiment

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The Arabian Sea is subject to extreme changes in atmospheric forcing that produce enormous seasonal changes in the upper layers. The U.S. Joint Global Ocean Flux Study (U.S. JGOFS) Arabian Sea Process Experiment collected arealy extensive, high-quality hydrographic data over more than a monsoon cycle between September 1994 and December 1995. We give an overview of hydrographic data that were collected and relate changes to the surface forcing associated with seasonal reversals in the monsoonal winds, and an attempt is made to highlight features of the variability that may be important to the interpretation of the U.S. JGOFS Arabian Sea Process Study. The complex water mass structure is due to advection and interleaving of water masses, and to formation of high-salinity waters in the Red Sea, Persian Gulf and northern portion of the basin which sink to moderate depths in the central basin. Perhaps the most surprising feature was widespread occurrence of moderately high nutrient values during the late NE Monsoon.

RSP-07: Variability of Chlorophyll Fluorescence, Euphotic Zone Depth, and Primary Production in the Arabian Sea during early NE monsoon, and SW monsoon periods

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Seasoar observations of physical and bio-optical variables in the Arabian Sea were used to examine the spatial variabililty of euphotic zone depth, chlorophyll distribution, and estimated primary productivity during 3 cruises that included early NE monsoon, SW monsoon, and late SW monsoon periods. Euphotic zone depth was estimated indirectly using the relationships between Kpar, beam attenuation (C660), and chlorophyll fluorescence to allow for estimation of euphotic zone depth for nighttime as well as daytime observations. Primary production was estimated from the seasoar data by applying photosynthesis-irradiance relationships measured experimentally in shipboard incubaitons to the Seasoar chlorophyll estimates and Kpar relationships. During the early NE monsoon period, chlorohpyll and primary productivity were higher than was expected but appeared to be coupled with the convectively driven nutrient flux and variability occurred at relatively small scales. During the early SW monsoon (June-July 1995) variability was strongly coupled with an upwelling filament. Late in the SW monsoon in September-October, high biomass and productivity was still observed over much of the region, but was less structured than during the early SW monsoon period.

RSP-08: How Deterministic is the Arabian Sea Circulation? A Look at Three Coastal Features

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Results from parallel runs of the Naval Research Laboratory(NRL) Layered Ocean Model with and without altimeter data assimilation--together with in situ and remote observations---are utilized to examine the deterministic nature of three coastal features in the Arabian Sea. The three features are the Laccadive High in 1994, the Great Whirl in 1995 and 1996, and the Oman coastal filaments in 1995. The model simulations utilize the global configuration at 1/4 degree resolution. The simulated movements of the Great Whirl during the Southwest monsoons of 1995 and 1996 are compared with results from a current meter array deployed from March, 1995 to October, 1996. An AXBT survey and altimeter observations are used to evaluate the simulations in the Laccadive High region, whereas AVHRR images are utilized to locate the positions of the major coastal filaments off the Oman coast. The results reveal that only the assimilative run is able to represent the correct phasing of the Laccadive High eddies in 1994 as well as the interannual variability of the Great Whirl characteristics in 1995 and 1996. Both types of simulations had difficulty depicting the specific location of the Oman coastal filament during the SW monsoon of 1995.

RSP-09: Wind Stress Curl Anomalies in the Arabian Sea, 1977-1996

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Wind stress and wind stress curl are analysed for the Arabian Sea for the period 1977 through 1996, encompassing the Arabian Sea Process Study period. Wind pseudostress is obtained from the Center for Ocean-Atmosphere Prediction Studies at Florida State University and is derived from an objective analysis of all available ship observations. Wind stress during the southwest monsoon of 1995 for the region of the Arabian Sea Process Study is found to be lower than the 1977-1996 mean by approximately 10%, while wind stress curl is lower by 50%. A numerical ocean circulation model dirven by these winds shows anomalously deeper thermocline off the coast of Oman during the southwest monsoon of 1995 due to decreased Ekman pumping.

RSP-10: Dynamics and Biology of a Cool Filament off the Omani Coast during the 1995 Southwest Monsoon

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During the Southwest Monsoon, coastal filaments are prominent features in remotely sensed sea surface temperature images of the northwestern Arabian Sea. Strong currents associated with these filaments may play a critical role in moving coastally upwelled waters offshore, and several modeling studies suggest that such transports exert a significant influence on the biological response to the Monsoon. SeaSoar surveys and intensive hydrography provide a detailed, three-dimensional picture of the physical and biological structure of a cool filament extending off the Omani coast during the 1995 Southwest Monsoon and facilitate an investigation of its dynamics and possible source regions. Decreasing nutrients and increasing nitrate/silicate ratios indicate that phytoplankton biomass and composition changes within the filament result from both

physical and biological processes. Watermass and biological distributions suggest that filament waters subduct as they move offshore. We will examine the filament's momentum and potential vorticity balances, assessing the degree to which its dynamics depart from geostrophy and attempting to make estimates of associated secondary circulations.

RSP-11: Remote Sensing of Coastal Upwelling and Filaments off the Coast of Oman

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Filaments transport upwelled waters from coastal Oman offshore to the open-ocean basin. Filaments were observed off the coast of Oman during the 1995 monsoon from May through September at three specific coastal headlands. Weekly composite AVHRR sea surface temperature imagery were used to characterize the size, shape, and temperature of these filaments which are typical features during the SW monsoon time period (observed in 1994 and 1996 imagery). The Masirah filament is estimated to maintain a transport of 5-7 Sverdrup for a 2.5-month period. Filament widths (150 km) and their extension offshore (400-km) reached a maximum in June during the SW monsoon. Filament properties have elevated chlorophyll, and beam attenuation coefficient which are characteristic of coastal upwelled waters. The calculated filament transport (based on numerical model simulation) represents a significant flux of offshore waters into the central basin. Filament temperature derived from the AVHRR imagery, shows coldest waters were during highest wind magnitudes of the SW monsoon, and suggests that upwelling strength and offshore transport are associated with the wind magnitude. As these upwelled waters are advected offshore, the filament characteristics change through mixing with offshore waters. The long-term offshore transport of coastal upwelled water by these filaments influence the bio-optical properties of the central Arabian Sea basin.

RSP-12: Relating pigments and optical signatures in coastal and open-ocean waters of the northwest Arabian Sea

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We describe the variability of the light field at upwelled coastal and open-ocean stations in the northwest Arabian Sea and relate this variability to phytoplankton compositional changes. Optical instrumentation deployed during September/October 1995 (post-SW monsoon) included: a field spectroradiometer for hyperspectral above-water remote sensing reflectance (Rrs) measurements; a K-chain for estimates of the diffuse attenuation coefficient at a single wavelength (Kd532 nm); a tethered spectral radiometer buoy (TSRB) for surface Rrs measurements at seven wavelengths; and a SeaWiFS profiling multichannel radiometer (SPMR) for depth profiles of upwelling radiance and downwelling irradiance at thirteen wavelengths. The SPMR data were used to derive spectral depth profiles of Rrs and Kd. In addition, phycoerythrin-containing picoplankton were characterized and enumerated using scanning fluorescence spectroscopy. Phycourobilin:-phycoerythrobilin (PUB:PEB) ratios were calculated to test a previous hypothesis that high ratios are indicative of open ocean assemblages (low Kd443), and low ratios are indicative of coastal assemblages (high Kd443). We relate the variability in the optical environment to changes in phytoplankton concentration and HPLC-determined dominant accessory pigments.

RSP-13: Bio-Optical Variability in the Arabian Sea and the Gulf of Oman during British and US JGOFS Cruises (Aug 1994 - Dec 1995)

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Bio-optical properties were measured in the Arabian Sea and the Gulf of Oman during two British and five US JGOFS cruises (August 1994 to December 1995). To accurately describe the temporal and spatial variability of bio-optical properties spectral upwelling and downwelling irradiances, spectral upwelling radiance, natural and stimulated fluorescence, beam atteunation at 660 nm, and particulate spectral absorption were measured during these cruises. Remote sensing algorithms have been developed relating water-leaving radiance ratios to diffuse attenuation coefficients, HPLC measured pigments and the particulate absorption coefficients. Pigment specific absorption coefficients have been cal-

culated to determine horizontal, vertical, and seasonal variability in this parameter. Preliminary results indicate that the vertical distribution of bio-optical properties can be estimated from near surface remotely sensed ocean color in this dynamic area.

RSP-14: Pigment Absorption and Primary Production during the spring intermonsoon in the Arabian Sea

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Phytoplankton pigment absorption spectra were computed from both pigment reconstructions and filter-pad particulate absorption, and then weighted by the in situ spectral quality as a function of depth. For the same day, in situ carbon assimilation measurements were made using the 14C technique. As long as absorption by non-photosynthetic pigments is accounted for, reasonable estimates of primary production as a function of depth, P(z), are found from the product of (1) (an assumed) quantum yield, (2) phytoplankton absorption (weighted by the spectral quality of the water), and (3) total daily (PAR) irradiance. Our analysis suggests that differences in phytoplankton absorption are more important than variations in quantum yield in estimating primary production.

RSP-15: Spatial Patterns in Phytoplankton Growth and Microzooplankton Grazing in the Arabian Sea during Monsoon Forcing

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Spatial patterns in the distributions of populations and the rates of phytoplankton growth and microzooplankton grazing were investigated in the Arabian Sea during the Southwest Monsoon (August-September) and early Northeast Monsoon (December) seasons in 1995. Nutrient-enhanced growth rates, as estimated by the seawater dilution technique, averaged 1.2 d-1 in the upper euphotic zone for both cruises and were similar between higher and lower nutrient stations, the former (> 1.0 μM NO3) being characteristic of the upwelling-influenced western coastal portion of the study region and the latter (< 0.5 μM NO3) being typical of the central basin. Growth rates without added nutrients were also comparable between cruises but strongly related to ambient nutrient conditions, averaging 1.1 d-1 at the higher nutrient stations and 0.5 d-1 at the lower nutrient stations. The rate estimates for phytoplankton losses to microzooplankton grazing averaged 0.6 d-1 for the upper euphotic zone and did not vary systematically between low and high nutrient stations. As a consequence, growth and grazing were largely in balance for the oligotrophic stations, while the eutrophic stations showed a growth differential over grazing of about 0.6 d-1. These experimental results are consistent with observed differences in community structure, namely the dominance of picophytoplankton in the oligotrophic offshore regions and the increased importance of the large diatom - mesozooplankton grazing pathway in the richer coastal areas.

RSP-16: Distribution, annual cycle, and vertical migration of acoustically derived biomass across a 900 km transect in the Arabian Sea during 1994-1995

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Seasonal cycles in the standing stock of zooplankton and ichthyoplankton in the Northern Arabian Sea are influenced profoundly by the ocean's response to oscillating monsoon winds. Upwelling of nutrient rich water during the SW monsoon enhances production while convective mixing during the NE monsoon also is associated with increased productivity. The vertical distribution and abundance of biomass was estimated using an acoustic Doppler current profiler along a 1000 km in the northern Arabian Sea during the U.S. JGOFS Arabian Sea Process Study. A buildup of biomass in the upper water column inshore of the Atmospheric Findlater Jet was observed during the SW monsoon when biomass was 1.5 times greater than that observed during the NE monsoon. Offshore of the jet, the contrast in biomass between the two seasons was reduced. Multivariate principal component analysis demonstrated associations between physical and chemical parameters and between biomass and chlorophyll, but not between physical/chemical and biological parameters. Significant diel vertical migration, likely originating from mytophids, was observed in the data, with the timing closely associated with sunrise or sunset. Diel vertical migration was more cohesive, with greater velocities, during the NE Monsoon than the SW monsoon.

RSP-17: Grazer Control of Carbon Flux Early in the Southwest Monsoon Season in the Arabian Sea

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Peaks in fluxes of organic carbon and biogenic silica within 350 kilometers of the Omani coast in the Arabian Sea occur in August-September, well after the onset of upwelling-favorable winds in May-June and cool sea-surface temperatures in June-July. The community structure of the mesozooplankton within 350 kms of the coast changes markedly, with the addition of ontogenetically migrating species such as Calanoides carinatus and Eucalanus crassus in the upwelling area during the Southwest Monsoon season. In the Northeast Monsoon, the community is dominated numerically by Oithona and Oncaea species. The ontogenetically migrating species, which occur mostly in the upper 75 meters in the SW Monsoon, are large-bodied copepods whose diet includes larger phytoplankton taxa, particularly diatoms. The presence of these taxa in the upper layer early in the upwelling season provides grazer control of the diatom bloom. It is only after these taxa complete their life cycles in the upwelling area, and leave the upper layer on their annual ontogenetic migration to depth, that flux of biogenic silica is measured in the sediment traps.

RSP-18: Volume and salt flux through the Bab el Mandab Strait: Two years of observations, 1995-1997

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Exchange flow between the Red Sea and Gulf of Aden-Indian Ocean through the Bab el Mandab Strait was measured continuously from June 1995-January 1997. ADCP, conventional current meters and temperature-salinity chain moorings allow an unprecedented look at the magnitude and seasonal evolution of the inflow layer from the Gulf and the high salinity outflow layer from the Red Sea. Timing, structure, and evolution of the summer mid-depth intrusion of cold, low salinity water into the Red Sea from the Gulf is measured for the intrusion cycles of 1995 and 1996. We find the deep outflow is strong in June 1995. From July to September, deep outflow persists but is attenuated. The dominant summer feature, cold low salinity intermediate layer intrusion, persists for 3 months and carries cold nutrient-rich water to the Red Sea. Salinity transport computations allow estimates of basin-wide evaporation rates. Winter regime begins in September, is fully developed by November, and continues to March 1996. Lower layer speeds are 0.8-1.0 m/sec; upper layer is 0.4-0.6 m/sec. At maximum exchange in February, outflow transport reaches 0.7 Sv. Recent computations of evaporation rates and salt flux balances are consistent with layer transports made from velocity measurements only.

RSP-19: Observations of Seasonal Exchange through the Strait of Hormuz

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The exchange between the Persian Gulf and the Arabian Sea is investigated using moored Acoustic Doppler Current Profiler (ADCP) and temperature-conductivity chain data from the Strait of Hormuz during December 1996 to March 1998, together with hydrographic and velocity profile sections across the strait. The moored time series records show a relatively steady deep outflow through the strait from 40 m to the bottom with a mean speed of approximately 20 cm/s. A variable mean inflow is found in the upper layer with frequent reversals on time scales of several days to weeks. The salinity of the deep outflow varies from 39.3 to 40.8 PSU with highest outflow salinities occurring in the winter months (December-March). During summer a very warm (30-31 C) and salty (40 PSU) shallow outflow also occurs on the southern side of the strait which is likely derived from the highly evaporative shallow shelf region along the southern Gulf. The mean outflow transport of saline Persian Gulf water is estimated to be 0.28 Sv, somewhat larger than the 0.2 Sv annual mean exchange typically estimated from Knudsen balances for the Persian Gulf. A preliminary analysis of wind and tidal forcing over the southern Gulf will also be presented.

RSP-20: Hydraulic Interpretation of Direct Velocity Measurements in the Bab al Mandab

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ADCP velocity measurements in the Bab al Mandab during the period June 1995-March 1996 are used to assess the hydraulic character of the exchange flow at the Hanish Sill and Perim Narrows. We use a three-layer approximation of the monthly mean velocity and density structure at each location to calculate the phase speeds of the first and second internal, long gravity

waves. The calculation takes cross-strait typographic variations into consideration by using a piecewise linear representation of the actual bottom topography. The resulting phase speeds are used to determine whether the flow is subcritical, supercritical, or critical with respect to the first and second internal modes. We find little evidence of hydraulic control with respect to the first vertical mode during any month. For the second internal, hydraulic control appears to exist during the winter. The wave whose propagation is arrested is one attempting to move from the Gulf of Aden into the Red Sea. The vertical structure of this wave suggests a role in determining how much Red Sea Deep water is able to cross the sill and flow into the Gulf of Aden.

RSP-21: Semi-anoxic Conditions in the Elefsis Bay, a Greek Marine Bay in the Aegean Sea: Recent Results

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Semi-anoxic conditions were examined in the Elefsis bay, a marine bay in the Saronikos gulf of the Aegean Sea in central Greece. The concentration of dissolved oxygen and nutrients have been determined during seasonal surveys. Anoxic conditions were observed in the water masses below 20m due to stratification during summer, while the water masses were found to be well mixed during the winter. We examined the processes of nitrification and denitrification as well as the distribution of nutrients N, P and Si. The relations between the accumulation of nutrients were discussed. Comparison of nutrient levels in Elefsis bay and in other coastal waters of the Aegean Sea was carried out.

RSP-22: Ventilation of the Black Sea Pycnocline

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The Black Sea is an estuary type basin where water of the Bosporus undercurrent when mixed with the ambient fluid permeates into and below the pycnocline, a layer of about 100 m thickness separating oxic and anoxic environments. The problem of a balance between advection and diffusion within this layer is one of the pivotal issues of Black Sea oceanography. Here, this problem is tackled from the basis of data analysis. The focus is on long term variations in thermohaline structure of the pycnocline where traces of winter mixing events are well preserved due to the peculiarities of the Black Sea, where temperature acts as a passive tracer with a smaller contribution to density as compared to salinity. The study is based on recent data sets depicting normal, severe and mild winter conditions. Vertical distribution of magnitudes of temperature oscillations indicates that convection events have limited effects in modifying the pycnocline structure on a seasonal time scale. However, long term (5 to 10 years period) fluctuations are well recognized. Regional peculiarities in physical and chemical responses to variable winter conditions allow us to infer that the lower pycnocline of the Black Sea is continuously ventilated through lateral injection of waters of the Bosporus plume, whereas, an effective ventilation of the upper pycnocline occurs episodically (once in two to ten years) due to extreme winter cooling at the surface.

RSP-23: Hydrodynamically Dominated Ventilation of Anoxic Waters and Fate of Chernobyl Radionuclides in the Black Sea

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We report here investigations of the energy-and-mass exchange processes that determine ventilation of the Black Sea anoxic waters and propagation of pollution in the bottom boundary layer of the Black Sea. Special emphasis has been put on possible propagation of Chernobyl radioactive substances via physical mechanisms such as the global circulation, near-bottom gravity and turbidity currents, internal waves, large-scale eddies and chemical processes in near-bottom layer. One of the key problems in this study has been the modeling of mechanisms of the backward transport of radionuclides during bottom storms from deep water regions toward the beaches and surf zone of the Black Sea. We have investigated the near-bottom density and turbidity current diagnostics and calculation methods for the forecast of these flows on radionuclide transport. Such currents may be catastrophically powerful and may contaminate surrounding waters over tens of meters above the bottom level. The elaboration of current structure diagnostic methods based on the results of spectra analysis of suspended particle size and of current parameter distributions measurements have been performed both in depth and in time.

RSP-24: Black Sea interdiscipline database: tool to study regional processes

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A Black Sea interdisciplinary historical database has been created within the framework of the NATO TU-BLACK SEA Project for which prominent regional oceanographic institutions provided more than 13,000 data files (150 MB). The database includes 116 basic physical, chemical and biological variables for the entire Black Sea (8,364,731 data value, 26,035 stations). It spans the period of recent adverse alterations of the Black Sea ecosystem starting from the background situation of 1950-60s to present. The most covered period is 1976-1996. The database can be used to study large- and mesoscale processes. All data were quality checked by qualified regional experts and each data value is accompanied by a quality flag. A special unique DBMS was developed to work with large sets of interdisciplinary oceanographic data (under Windows-95). It gives the user a lot of possibilities for quick and comfortable work with the entire database. One can view, process, sort, select, and export all necessary data and metadata using user friendly multi-windows interface (including many graphical possibilities: maps, profiles, histograms, etc.). Comparison of this database and some well-known recent datasets reveals it as the first successful undertaking to create a regional historical interdisciplinary multipurpose database. This database and DBMS can be used as a basis for new oceanographic and environmental projects in the Black Sea region and as an example for other regions.

RSP-25: Tracer Experiments in the East China and Yellow Seas

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The Yellow and East China Seas are a continental shelf area where the warm saline tropical origin Kuroshio water mixes with rather fresher coastal water. Because the area is mid-latitude, seasonal variations of oceanographic parameters are dramatic. To investigate the origin and mixing of water masses in this area, a numerical model experiment was composed using a tracer. The POM based Yellow Sea model was updated to incorporate an advection of a tracer. The tracer used in the experiment is an arbitrary tracer which can be released at any interested place in the model domain. A tracer was released at the Kuroshio inflow boundary (east of Taiwan) and at the Taiwan Strait so that the effect of two major warm and saline water sources may be investigated. The model experiment was repeated for the case of no wind to test the influence of wind forcing in the formation and mixing of water masses. Results of the experiment are depicted in 20 m, 50 m, 100 m, and 200 m depth tracer concentration contour plots and compared.

RSP-26: Observed and modeled pressure response of the Yellow and East China Seas to wind forcing

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We use observed sea surface height variations from the TOPEX/POSEIDON (T/P) altimeter, in situ pressure gauges, and numerical model to understand the ocean response. The T/P data is used in a statistical regression since the altimeter temporal sampling is 10 days, longer than the time period of most events. The wind stress from NOGAPS is decomposed through an EEOF analysis. The statistical SSH response observed from T/P is constructed to these EEOF modes. The numerical model forced by NOGAPS winds is used to construct a similar response, and the numerical model response to the EEOF modes compares well with the altimeter observed response. The statistical model and the numerical model results both compare well with in situ pressure gauge moorings in the Yellow Sea. The frequency spectra of all the time series indicate peaks at 3 and 7 days. An EEOF analysis of the SSH itself reveals one of the fundamental responses of the Yellow and East China Seas to short time period northerly wind bursts. The winter wind bursts produce a large SSH anomaly in the Bohai Bay and northern Yellow Sea. The SSH anomaly subsequently propagates southward along the Chinese coast at a speed of 12 m/s. Analytic solutions to continental shelf waves indicate that the gravest (Kelvin) mode wavelength matches well with the observed wavelength.

RSP-27: A Study of the Wind Induced Transports into the Yellow Sea

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The Yellow Sea warm current is observed as a northward flow of warm water, occurring primarily during the winter, in the deeper part of the Yellow Sea. Several studies in the literature have indicated a correlation with northerly winds in generating this signature. A version of the Princeton Ocean Model forced with daily atmospheric fields from Fleet Numerical Meterology and Oceanography Center's (FNMOC's) Navy Operational Global Atmospheric Prediction System (NOGAPS) is used to simulate the circulation in the Yellow Sea/East China Sea region. An analysis of model generated currents in response to a northerly wind is

used to deduce the primary forcing mechanisms for the Yellow Sea warm current. A north/south pressure gradient develops as water is pushed out of the Bohai bay by the northerly winds, decreasing the elevation in the north relative to the elevation in the south. A southward flowing current along the Chinese coast develops as fluid moves out of the Bohai Bay. This coastal current increases in strength as the northerly wind event moves southward. The coastal current is further strengthened by geostrophic flow generated by east-west pressure gradients created by a wind induced set-up along the Chinese coast and set-down along the Korean coast. A southward current along the Korean coast results from the set-down along this coast. Flow northward, opposite the wind, in the deeper part of the Yellow Sea occurs in response to the north/south pressure gradient and to the east/west pressure gradient. In this study, we try to determine the relative importance of the pressure gradients, wind stress, and geostrophic adjustment in influencing the flow into and out of the Yellow Sea.

RSP-28: Modeled and Measured Currents in the Yellow Sea

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Measurements of currents in the Yellow Sea are very difficult to obtain due to the intense level of fishing and trawling. Hence, such measurements are relatively scarce. A new technique for mooring acoustic doppler current profilers (ADCPs) on the bottom has been utilized by the U.S. Naval Oceanographic Office. In 1995, they deployed three ADCPs in the Yellow Sea interior, incorporating "trawl resistant" instrument mounts. The resulting current profiles are used to estimate the low frequency currents and the depth dependent tide structure. These direct current measurements are analyzed in conjunction with a numerical model developed at the Naval Research Laboratory. The model is based on the Princeton Ocean Model and contains enhancements to vertical mixing. The horizontal grid is rectilinear with variable spacing ranging from 8 to 25 km. There are 24 sigma levels in the vertical, with closer spacing between sigma levels near the surface and bottom. Realistic bathymetry based on ETOPO5 and atmospheric forcing from NOGAPS winds are used.Results show that currents in the Yellow Sea are dominated by the tides. Mean detided currents are relatively small, ranging from 2 to 4 cm/s. Currents are found to be most depth dependent in the near-surface and near-bottom layers. Approximately 85 to 90% of the eddy kinetic energy in the mean is depth independent.

RSP-29: Heterogeneity induced by vertical mixing and turbulence

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In the eastern English Channel, generally considered a homogeneous system owing to tidal mixing in shallow waters, vertical distribution of photosynthetic parameters of phytoplankton, chlorophyll a, nutrients, and hydrodynamic properties were investigated during several tidal cycles, in neap and spring tide conditions, in nearshore, offshore and intermediate waters. We then showed that environmental parameters typically implicated in primary production and photosynthetic parameters displayed vertical heterogeneities, with relatively different spatial patterns whatever the tidal conditions. As a matter of fact, temperature, salinity and nutrient concentrations showed usually low vertical heterogeneities, independently of encountered tidal conditions or sampled water masses, and without vertical gradient consistent with a biological activity. On the contrary, photosynthetic parameters displayed more or less pronounced vertical heterogeneities, controlled by mixing at the scales of the semi-high-low tidal cycles and neap-spring tidal cycles, and by the sampled water column depths. Vertical gradient of photosynthetic parameters were furthermore the results of cell physiological adaptation processes. If vertical and temporal heterogeneities of photosynthetic parameters were not taken into account in daily primary production rate computations, it results in differences in daily production rates ranging between 2.6 and 100% according to the case study.

RSP-30: On the seiche event in the Adriatic Sea on 20 December 1997

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The poster reports an analysis of a marked longitudinal main seiche of the Adriatic Sea, which occurred on 20 December 1997 and was recorded by tide-gauge stations of Trieste (Italy) and Bakar (Croatia). The seiche was generated by southerly wind (Sirocco) which was induced by a dipole-like pressure field with a cyclone over western Europe and an anticyclone over Anatolia. Locally, the atmospheric pressure exhibited a marked decrease until 12:30 on 20 December, then a progressive increase. At both stations, the residual sea level dis-

played a strong peak coinciding with the pressure minimum, followed by pronounced, damped oscillations persisting for about a week. Spectral analysis of residual sea level for both stations gives a main peak at 21.2 hours, corresponding to the fundamental longitudinal seiche of the Adriatic, and another one at about 10.5 hours, which could be attributed to the second mode. Decay time associated with the main oscillation is 80.4 +/- 6.7 hours from Trieste data and 45.3 +/- 4.0 hours from Bakar data. This pronounced difference remains an open question, probably related to the influence of atmospheric forcing, after the seiche was generated, on the apparent decay of the fundamental mode.

RSP-31: Time Flow Variability in the Balearic Channels and Its Relevance for the Western Mediterranean Circulation

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Five instrumented moorings have been deployed in the Balearic channels, repeated hydrographic surveys have been carried out and AVHRR satellite images have been analysed during 1996 and 1997 to study the meridional fluxes between the (thermo)dynamically well contrasted northern and southern Mediterranean and assess their time variability. The flow regime is basically characterized by the southward advection of Levantine Intermediate Waters and the northward intrusions of Modified Atlantic Waters in the surface layer. Transient mesoscale eddies are observed to sporadically produce important fluctuations in the transport of both water masses. The interannual and seasonal variability is found to be mainly controlled by the presence or not of persistent large Winter Intermediate Water eddies (Weddies) in the channels area in spring-summer, depending on the heat loss and convection processes in the northern Balearic Sea in winter, which can lead to a major blocking of the water exchange. All transport estimations with the associated errors are carefully done by integrating synoptic currentmeter and CTD data using inverse models based on the geostrophic assumption and conservation of mass, salt and heat content in closed boxes. The relevance of the results for the general circulation of the Western Mediterranean is discussed.

RSP-32: Interaction of Florida Bay waters with the Gulf of Mexico and the Atlantic Ocean

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As part of the South Florida Ecosystem Restoration program, an observational study of the circulation of Florida Bay and its connection with the surrounding waters of the Gulf of Mexico, the southwest Florida shelf, and the Atlantic Ocean is presently underway. Measurement systems include moored arrays equipped with current meters, bottom pressure sensors and conductivity-temperature sensors; satellite-tracked surface drifters; and shipboard ADCP. Bimonthly interdisciplinary surveys include continuous thermosalinograph observations of surface salinity, temperature, and fluorescence. Early results show that there is a net southeastward flow of 1 to 4 cm/s which transports waters from the Gulf of Mexico and the Everglades across western Florida Bay and through the channels of the Florida Keys, on a time scale of 1 to 3 months depending on local wind forcing. This net flow, with a volume transport of 1000 to 2000 m3/s, has the potential to deliver harmful algal blooms and excess nutrients out to the environmentally sensitive coral reefs of the Florida Keys National Marine Sanctuary. The ongoing study now focuses on refining and quantifying the flow between the Gulf of Mexico, Florida Bay and the Atlantic and its response to seasonal and episodic meteorological forcing. In addition, new emphasis is placed on examining the fate of the freshwater river discharges from the Everglades into the Gulf of Mexico, and the relation of the river plume dispersion to regional wind and rainfall distributions.

RSP-33: Springtime Structure of the Shelfbreak Front in the Middle Atlantic Bight

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During early May, 1996, an intensive hydrographic study of the shelfbreak front in the Middle Atlantic Bight was conducted using the WHOI SeaSoar. Four cross-frontal transects were sampled which spanned the front. Winds were light during the study period, and the front was relatively straight and not contorted by instabilities or offshore forcing. The cross-frontal sections reveal strong gradients across the front extending from the surface to depths of 60 to 80 m. The contrasts across the front were as large as 5 degrees C and nearly 2 psu in salinity. The cross-shelf density gradients were strongest at the surface, with density contrasts of 0.6 kg/m^3 over a few kilometers. Lateral density gradients were also strong near the foot of the front. Shipboard ADCP measurements as well as geostrophic velocities suggest two separate westward alongshelf

jets associated with the frontal structure, with one near the surface outcrop and one near the foot of the front. Property distributions near the surface outcrop of the front suggest a downwelling circulation, with more dense slope water being drawn under the front. However, near the foot of the front, there are convergent velocities within the bottom boundary layer, suggesting upwelling. This is consistent with previous numerical models of the front, indicating bottom boundary layer detachment should occur within the frontal zone.

RSP-34: Are Nutrients a Problem in Estuarine and Coastal Waters?

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Most of the estuarine and coastal waters of the world have experienced nutrient enrichment from urban, agricultural, and industrial activities. Higher than natural nutrient loading is usually interpreted as undesirable and is associated with excess algal production and harmful algal blooms. However, all estuarine and coastal waters do not react in the same fashion to nutrient enrichment and many waters show much lower algal production than could be supported by nutrient availability. Some waters, such as the Delaware Estuary (USA), have very high nutrient inputs without problems from excess algal production nor from harmful algal blooms. Thus, it is suggested that we rethink the association with nutrient enrichment and algal production. Several important considerations should be made in this rethinking: 1. The discrepancy between nutrient loading and nutrient concentrations in the receiving waters, 2. Differences in ratios of major and micronutrients in various estuarine and coastal environments, 3. Apparent inhibitory or stimulatory influences from other inputs coming into estuarine and coastal waters along with nutrient enrichment. Temporal (seasonal and long time series) and spatial studies in the Delaware Estuary will be used to address the association between nutrients and algal production with comparison to other estuarine and coastal environments.

RSP-35: Transport Pathways of Sea Ice Formed in Arctic Coastal Seas

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This study uses a numerical model to investigate the pathways taken by sea ice parcels originating in coastal waters. The motivation for this study was the need to investigate the possible transport pathways of radioactive contaminants dumped into coastal waters and then entrained into the newly forming sea ice. A coupled ice-ocean model used as the basis for the U.S. Navy's sea ice forecasting system, the Polar Ice Prediction System (PIPS), has been run using daily atmospheric forcing from the Navy Operational Global Atmospheric Prediction System (NOGAPS) for the five year period from 1992-1996. The model is the Hibler ice model coupled to the Bryan-Cox ocean model. The model domain encompasses all of the sea ice covered regions of the northern hemisphere using a 0.25 degree grid. Each model grid cell containing sea ice is considered to be a "parcel" which is tracked through the 5 year simulation. The "track" terminates either when the ice parcel melts or when it runs into land. Results indicated that most parcels originating in the coastal regions adjacent to the former Soviet Union either exit through the Fram Strait (i.e. those originating in the Laptev and East Siberian Seas) or remain in these coastal waters (i.e. those originating in the Kara and Barents Seas). The majority of ice parcels originating in the Beaufort and Chukchi Seas remain there for the duration of the 5-year simulation. These results agree with recent statistics calculated from drifting buoy data and provide additional information in those coastal regions not covered by the drifting buoy data.

RSP-36: Evidence for a Substantial Increase in Biomass of Gelatinous Zooplankton in the Bering Sea: Possible Links to Climate Change

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We examined quantitative catches of large medusae from summer bottom trawl surveys which used the same methodology and sampled virtually the same station grid (n= 346) on the eastern Bering Sea shelf from 1979 to 1997. This series shows a slight increase in biomass of medusae from 1979 to 1989, followed by a dramatic increase in the 1990s. The median biomass per station increased ten-fold between the 1982-89 and 1990-97 periods. The majority of this biomass was found within the Middle Shelf Domain, with a higher rate of increase in the Northwest shelf region. Whether this dramatic increase in biomass of gelatinous zooplankton has resulted from some anthropogenic perturbation of the Bering Sea environment or is a manifestation of natural ecosystem variability similar to that seen in other ecosystems is unclear. However, several large-scale winter/spring atmospheric (pressure indices, storm tracks) and oceanographic variables (temperature, water col-

umn stability) in the Bering Sea exhibited concomitant changes beginning around 1990, possibly indicating that a regime change occurred at this time.

RSP-37: Fronts and Fish: Interannual and Regional Differences in Frontal Structure and Effects on Pollock and their Prey

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A tidal front exists around the Pribilof Islands in the eastern Bering Sea which separates well-mixed nearshore water from the strongly stratified middle shelf water farther offshore. Enhanced mixing of nutrients at the structural front results in high abundances of phytoplankton, zooplankton and micronekton. We examined interannual and between-habitat differences in abundance, distribution, size composition, age, growth, and feeding habits of age-0 walleye pollock in relation to the physics and biology associated with fronts north and south of the islands during September of three hydrographically contrasting years. The frontal region occurred at similar locations offshore during all years, but thermocline depth varied greatly. Highest chlorophyll and small zooplankton concentrations occurred seaward of the front and were lower both inshore and offshore of the front. Large zooplankton (euphausiids and cnidarians) were abundant in the stratified offshore waters. Pollock numericallu dominated the catches of midwater trawls along this transect, although cnidarians dominated the biomass. Pollock densities were the highest at the front or inshore of the front but were variable by year. The smaller and younger pollock were inshore and at the front compared with those found offshore. Pollock consumed primarily copepods and euphausiids, although other prey (pteropods, chaetognaths, other age-0 pollock) were important at times.

RSP-38: Climate fluctuations and the abundance of Calanus finmarchicus in the North Sea

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Concentrations of overwintering Calanus finmarchicus in the North Sea do not appear sufficient to support abundances observed in the spring and it this study investigates whether the population may be sustained by invasion from an overwintering stock located beyond the shelf edge. The results show that the main source of overwintering animals entering the North Sea in the spring is at depths of greater than 600 m in the Faeroe-Shetland Channel, where concentrations greater than 100 m3 are found in association with the overflow of Norwegian Sea Deep Water across the Iceland-Scotland Ridge. The volume of this water mass in the Channel, and hence the overwintering habitat of C. Finmarchicus, has declined since the late 1960's possibly due to changes in convective processes in the Greenland Sea. Beginning in February, animals migrate to the surface waters where their transport into the North Sea is mainly determined by the incidence of northwesterly winds which have also declined since the 1960s. Together, these two factors explain a high proportion of the decrease in spring abundance of Calanus finmarchicus in the North Sea observed over the past 30 years.

RSP-39: Irish Sea water quality modeling: a 2D horizontal biogeochemical model for the Irish Sea

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The model DYMONIS (DYnamic MOdel of Nutrients in the Irish Sea) describes nutrients and phytoplankton dynamics in the Irish Sea between Saint Georges Channel at 52.02°N and the North Channel at 55.02°N. DYMONIS is a 2 dimensional-horizontal physical biogeochemical model with 634 pelagic boxes, each approximately 8km x 8km, 13 state variables, a time step of 2 hours in its diagenetic part and of 6 hours in its hydrodynamic and biological parts. DYMONIS provides a framework with which to test related to eutrophication issues in the Irish Sea and has been developed as part of the British programme JONUS II (JOint NUtrient Study II). The output from the model is compared to data from a variety of sources. Initial results show that the model predicts the occurrence of spring and autumn blooms in the western part of the Irish Sea, both of which have been observed. Parameter sensitivity analysis reveals that grazing pressure has a strong influence on phytoplankton dynamics.

RSP-40: Denitrification in the North Sea: Investigations using DYMONNS II (DYnamic MOdel of Nutrients in the North Sea)

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Recent estimates of sedimentary denitrification in the North Sea (0.3 - 0.6mM N m^{-2} y^{-1}) are lower than in other areas, but the relatively large area of the North West European Shelf makes it important in global budgets. For a biogeochemical model to be capable of successfully describing nutrient dynamics it must reproduce such features. Within the framework of a 2D hydrodynamic model, a biogeochemical model DYMONNS II) explicitly simulating both pelagic and diagenetic processes has been developed. An earlier version of the model (DYMONNS), which excluded benthic processes, showed good agreement (r^2=0.88) with seasonal observations of total DIN (NO_3- -N + NH_4-N) and annual rates of primary production. Existing ecosystem models of the North Sea that include the benthos, produce low denitrification rates as a result of calibration with fewer and older data that probably underestimate denitrification. Other North Sea models have relied on observed benthic nutrient fluxes or have ignored these processes altogether (this precludes investigations of long term inter annual variability in water quality parameters). This model, using a spatial resolution of 35 x 35km2, overcomes these limitations. Its process rates have been calibrated on a global data base and the model uses measured and reliable boundary conditions. Progress of our work is presented here.

RSP-41: Lipids, buoyancy and the seasonal vertical migration of Calanus finmarchicus

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The copepod Calanus finmarchicus is observed to remain in diapause for up to 5 months in the cold (<0.5°C) deep (>700m) waters of the Faeroe-Shetland channel on the northwestern approaches to the North Sea. While in diapause, it is observed that C. finmarchicus has very high lipid content; up to 80% of dry weight. The question we address here is how animals, high in buoyant lipid content, can remain in diapause, at depth, for an extended period of time. Corollary to this is how these lipids hinder and/or assist the animals in their seasonal vertical migration. Part of the answer is found in the physical properties of lipids. These have a thermal expansion and compressibility higher than that of seawater. Thus, depending on its relative composition (lipids/water/protein/ chitin), an animal that is positively buoyant in warm surface waters can become neutrally buoyant in cold deep water. We develop a three component physical model of a copepod to explore how and where it attains neutral buoyancy, how the lipid content can aid in its ascent, and what fraction of the lipids can be utilised during ascent in egg/gonad formation while maintaining observed ascent rates. As well as being an energy reserve, we show that rather than being a barrier to vertical migration, lipids serve as an important physical buoyancy regulator.

RSP-42: Influence of a Coastal Current System and Diurnal Sea Breezes on Recruitment of Lobsters, Gulf of Maine, NW Atlantic

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Lobsters (Homarus americanus) develop through three larval stages and a neustonic postlarval stage before they settle to the benthos. These stages can drift long distances between hatching and settlement in the Gulf of Maine because of slow development rates and a strong cyclonic circulation. Postlarvae are abundant at least 50 km offshore. In a seven-year study, most postlarvae arriving at a coastal recruitment site were in late molt cycle stages, indicating a period of development offshore followed by onshore movement. We used a climate-averaged, 3-D finite element circulation model with a diurnal summer sea breeze to examine transport effects on recruitment. We employed inverse solutions of the model to back-calculate the possible hatching locations of postlarvae recruiting in different areas, and forward solutions to examine length scales of transport at various points around the Gulf. We show that spatial differences in alongshore transport result in varying separations between spawners and new recruits and may contribute systematically to regional differences in productivity of the fishery. We also quantify the importance of onshore wind flow and the significance of being neustonic during the final stage of development.

RSP-43: A Globally Relocatable Tide/Surge Forecast System

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A globally relocatable tide/surge model, driven by winds from a globally relocatable mesoscale atmospheric model has been developed and is presently being tested and validated against tide station data. The

tide/surge models areboth 2- and 3-dimensional barotropic ocean models developed by Global Environmental Modeling Services (GEMS). These models are provided boundary conditions from the Grenoble global tide model. The mesoscale atmospheric model, also developed by GEMS, is a hydrostatic primitive equation model using sigma coordinates in the vertical. Although the model includes parameterization of the boundary layer, horizontal and vertical diffusion, cumulus convection, latent heating and radiation, its use in this system is limited to providing surface wind fields. Intitial conditions and boundary conditions for the atmospheric model are provided by the output of the Navy Operational Global Atmospheric Prediction System (NOGAPS) analysis and forecasts. Ocean bathymetry for this system, at a resolution of 5 minutes or greater, comes from the U.S. Navy database DBDBV. The land topography is provided at 3 minute resolution and is derived from a USGS data base. Model results from various locations around the globe are compared to coastal station data, mainly from the International Hydrographic Organization tidal constituents data base. Storm surge simulations, generated using historical cyclone data are also compared to observation. Future improvements to this system include data assimilation and upgraded global bathymetry data.

RSP-44: Regional Transport Covariability in the Northeast Boundary Currents of the Pacific Ocean: Subarctic vs Subtropical Gyres

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One of the central hypotheses of the US GLOBEC program in the Northeast Pacific is that the strengths of the eastern boundary currents in the Subarctic Gyre (the poleward Alaskan Current) and the Subtropical Gyre (the equatorward California Current) covary out of phase on interannual (ENSO) to interdecadal time scales. It is also hypothesized that this covariability is linked to changes in the strength and/or position of the West Wind Drift current, which flows eastward between the two gyres at approximately 45N-50N. The primary evidence for the covariability of the boundary currents comes from coastal tide gauge data, but the link to the West Wind Drift has not been tested. Altimeter data now provide the means of quantifying the covariability of the surface transports in all parts of the two gyres. Approximately five years of TOPEX/POSEIDON (T/P) data are used to show this variability on seasonal and (marginally) interannual time scales. Previous analysis of the first three years of T/P data revealed the covariability of the boundary flow in the gyres on seasonal time scales, with little connection to the West Wind Drift. This analysis is now extended to the longer data set and a preliminary analysis of the non-seasonal variability is included. The 1997-1998 El Niño dominates the non-seasonal variability and provides a first look at the covariability of the various currents during the onset of this event.

RSP-45: Observations of Inorganic Carbon and Nutrients in the Central California Upwelling System during the 1997-1998 ENSO Event

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Seasonal upwelling from March until October is responsible for much of the high primary production along the central California coast. ENSO events will therefore usually impact this upwelling region in the spring when the temperatures along the equator are slowly returning to normal. Due to the unusual timing of the current ENSO event, some effects may have been observed during the late summer and early autumn of 1997. Results from local cruises and quarterly regional cruises during 1997-1998 are being examined and compared with historical data and a local time series that started in 1989. In addition to the shipboard data, moorings have been providing a continuous record of physical and optical parameters. The sea surface partial pressure of carbon dioxide was also measured from these moorings during most of this event. Upwelling started exceptionally early in 1997. Elevated partial pressure of carbon dioxide and decreasing temperature were evident at one of the moorings in late February and a cruise in early March confirmed these indicators. As the year progressed, a warm anomaly developed and the partial pressure of carbon dioxide fell below atmospheric values and has remained there with very minor short-lived exceptions. River runoff from strong winter rains in this ordinarily dry region may be responsible for some of the carbon dioxide decreases in the late winter of 1998.

RSP-46: Interpreting and Assimilating Long Term Multi-Platform Information from a Temperate Coastal Upwelling Ecosystem

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While the coastal upwelling process and its biological and chemical consequences have been studied extensively, these studies have been sporadic in space and time. Input parameters needed for modeling coastal

ecosystem have been marginally available and long-term data sets for model validation and for characterizing climate change are lacking. In 1989 the Monterey Bay Aquarium Research Institute (MBARI) began an intensive study of the coastal upwelling system of central California. The studies used bi-weekly to monthly ship expeditions together with continuous observations from strategically placed moored and drifting platforms. Satellite observations of sea surface temperature and ocean color provide a synoptic spatial view of physical and biological properties. The results from these measurements provide insights into the process regulating biological production in a coastal upwelling ecosystem as well data for model input and validation. The present challenge is developing a comprehensive system that will require minimum human intervention, allow for less expensive collection and more effective assimilation of information.

RSP-47: A Method to Filter the Internal Waves on the Shelf

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A method to filter fluctuations in the hydrophysical characteristics of the continental shelf, caused by intense internal tides, is proposed. The method is based on a smoothing of the field of the characteristic analyzed with a filter, the parameters of which are determined by the shape of the spatial correlation function of the field pulsations. The filtering method was tested on data from a rapid oceanographic survey, conducted in an area of the monitoring polygon of the waters around Barra de Navidad. The survey was conducted on 25 and 26 November 1995, with an undulating CTD. In one day, 86 vertical profiles of temperature and salinity were obtained from nine transects perpendicular to the coast (survey area of 100' 25 km) to a depth of 100 m. The field measurements present an analytical shape obtained from an equation in which the elements describe the components: low frequency, pulsating and related to daily behavior. The results of the analysis of the initial temperature and salinity fields with respect to homogeneity and isotropy are discussed. The correlation functions of the field pulsations analyzed are more clearly observed in the thermocline. The characteristic scales are lower perpendicular to the coast than along it. Examples of smoothing the temperature and salinity field in the thermocline are given.

RSP-48: Internal and Tsunami Waves on the Continental Shelf on the Occidental Coast of Mexico

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The result of multiple measurements of the thermohaline structure of the waters in a hydrophysical polygon, on the central part of the occidental coast of Mexico, using a CTD probe. The studied region comprises a very narrow shelf, which is suddenly interrupted towards the American Central Trench. The thermohaline structure of the waters of the region is affected constantly by the short-period internal waves. The initial baroclinic perturbation propagates toward the coast and is transformed into groups of short waves on the shelf. The maximum height registered for waves in the groups is up to 20-25 m, with an average length of 4-8 km and a phase velocity of 0.4-0.5 m/s. Free-field tsunami wave measurements recorded after October 9, 1995, at 15:36 GMT, are discussed. Its epicenter was located in the ocean at coordinates 18°51.5'N and 104°8.4'W. Using pressure sensors installed in two-anchored submerged buoys, the amplitudes and periods of the tsunami waves along the open continental shelf were measured. It was discovered that the tsunami in route to the coast interacted with the stratified water layers, creating a very strong mixing at the border of the shelf close to the slope. The data recorded also showed that the quake generated a strong vertical displacement of the sea floor.

RSP-49: Water mass formation, upwelling and fronts in the Great Australian Bight

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The Great Australian Bight and adjacent waters are described through observations and modeling as a region of water mass formation from enhanced air-sea exchange in the coastal zone. The warm water formed in the summer months spreads offshore and eastward. It is shown that advection of warm water from the Leeuwin Current, which was previously believed to be responsible for the observed warming south of Australia, comes into play only towards the end of summer. The circulation is dominated by a wind driven anti-cyclonic gyre with strong upwelling in the east. The upwelling is not driven by the coastal wind but is a result of conservation of potential vorticity over a sloping bottom, which produces a shift of the gyre centre relative to the centre of

the wind system, resulting in upwelling through the bottom boundary layer. The southern limit of this circulation is the Subtropical Front, which south of Australia is found to bend strongly northward, weakening at the same time. Density compensation of temperature and salinity along the front is nearly complete, and the front is associated with very little transport.

RSP-50: The fate of coral and fish larvae in reef waters

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We used the extensive AIMS data on the physics and biology of Australia's Great Barrier Reef (GBR), Australia to calibrate a first-ever physics-biology model for fisheries recruitment in the GBR. The data show that the coral fish larvae arrive from upstream and aggregate near coral reefs, in spatial patterns correlated with body size and at densities that are not explained by hydrodynamic trapping. By contrast, pelagic fish larvae avoided reefs. The distribution of fish larvae around a coral reef was successfully reproduced by advection-dispersion models which included the larvae swimming towards reefs from 1-3 km at speeds related to body size and consistent with laboratory and field studies. Thus in the GBR dispersal is determined by directional swimming and the oceanography. Individual coral reefs are not self-sustaining units of population. Our findings offer for the first time in a coral reef environment anywhere in the world a science-based tool to manage reef fisheries by determining the key source reefs and recruitment rates. Based on this experience we suggest that managers should question if the assumption of passive dispersal and recruitment, which we found incorrect for the GBR, may also be invalid for other fisheries in the world both in tropical and temperate climates. Many of these fisheries are under threat of over-exploitation and collapse. Their management relies on computer models where the recruitment phase may be incorrectly modelled based on our experience in the GBR.

RSP-51: Zooplankton and micronekton stocks in sperm whale habitats in the Gulf of Mexico

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A calibrated 153 kHz narrow-band ADCP (Acoustic Doppler Current Profiler) was used to profile acoustic volume backscattering strength (VBS) in the upper 200 m during several cruises to characterize the medium scale and regional scale physical and biological oceanographic habitats of sperm whale populations in the Gulf of Mexico. ADCP data were gathered while on station and while underway along transects through different hydrographic regimes: Mississippi River outflow, cyclone-anticyclone (divergence-convergence) circulation pair, and continental margin outside these regimes. In addition, zooplankton and micronekton stocks were intensively sampled with a 1 m^2 MOCNESS and 6 m^2 IKMT. Although our nets were not large/fast enough to collect adult squid, the abundance of paralarval squid in our net collections is a proxy for the distribution and abundance of sperm whale prey. Empirical correlations between spatial and temporal variations in VBS, standing stocks of zooplankton/micronekton, squid paralarvae, and visual and acoustic contacts with sperm whales will be presented. This ongoing research is supported by the USGS Biological Resources Division and the US Minerals Management Service under USGS BRD contract #1445-C109-96-004. For more information, see http://www.tamug.tamu.edu/gulfcet.

RSP-52: Marginal and Coastal Seas in the AMAP Assessment of the Arctic Pollution Issues

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Arctic Monitoring and Assessment Programme (AMAP) was established in 1991 as an intergovernmental programme of the eight Arctic States with the objective to monitor, assess and report levels and trends of pollutants in the Arctic environment and their effects on ecosystems and humans. The first phase of AMAP has been finished in 1997 by presentation to the Ministerial Meeting (Alta, Norway) of the "Arctic Pollution Issues: A State of the Arctic Environment Report," which is supported by the more scientifically substantial "AMAP Assessment Report: Arctic Pollution Issues." The findings and recommendations of the AMAP assessment are to be taken into consideration by the Arctic States in their policies and programmes for remedial actions. The Arctic marginal and coastal seas have a special importance in the Arctic ecosystem due to their biological productivity. However, they are affected by all major sources of contaminantion of the Arctic marine environment: - atmospheric deposition on their surfaces; - marine inflow transport; - river discharge; - direct discharge from land-based sources; - dumping of hazardous wastes; - pollution from shipping activities. The poster presents the results of the AMAP assessment relevant to the Arctic marginal areas. Special attention is paid to pathways of contaminants, their fate and effects on ecosystems and humans, particularly indigenous populations.

MISCELLANEOUS TOPICS (MIS)

MIS-01: Testing dynamical hypotheses near the coast with a ship-mounted ADCP

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A generalized inverse of ship-mounted ADCP data can distinguish tidal and non-tidal flow. This can be accomplished with data from a single 10-hour survey. Data from ten such surveys were collected in Long Island Sound, a coastal region with strong tides. The survey data were collected with the intention of measuring the poorly understood general circulation of Long Island Sound. Support for the hypothesis that there is sub-tidal flow is obtained by showing that its converse (the null hypothesis of no such flow) is false. The inverse analysis incorporates a simple dynamical model for depth-averaged tidal flow. Errors in the prognostic calculation (the forward model) are too large to permit definitive conclusions. The inverse calculation allows for errors in dynamics and boundary conditions. Once these model errors are accounted for, the improved tidal model allows straightforward estimation of the non-tidal component of the data. Predictability studies verify that inversion of a single 10-hour survey improves the tidal prediction. Experiments with the same data show that tuning a friction parameter in the forward model reduces model-data misfit for hindcasts. However, in contrast with inversion, tuning actually degrades forecasts.

MIS-02: The West Florida Coastal Ocean Monitoring and Prediction System

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Florida is the Unites States' fourth most populous state, with 80% of the population living in a coastal county. Several recent storms have brought large, unpredicted flooding to Florida's west coast. The coastal sea level response to tropical and extra-tropical storms results from wind forcing over the entire continental shelf. Much of the local response may actually be due to storm winds quite distant from the local area of concern; a case in point being tropical storm Josephine, a modest storm that nevertheless caused extensive flooding in the Tampa Bay area. The University of South Florida is implementing a real-time Coastal Ocean Monitoring and Prediction System (COMPS) for West Florida that will provide additonal data needed to give more accurate predictions of ocean storms and coastal flooding by storm surge. This system consists of an array of instrumentation both along the coast and offshore combined with numerical circulation models and builds upon existing in-situ measurements and modeling programs funded by various state and federal agencies. This observing system fulfills all of the requirements of the Coastal Module of the Global Ocean Observing System (CMGOOS). Data and model products are disseminated in real-time to federal, state, and local emergency management officials via the internet (URL http://ompl.marine.usf.edu/WFLORIDA/).

MIS-03: Global Coastal Ocean Data, Access, and Display

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The mission of the Coastal Ocean Laboratory (COL) is to acquire global coastal ocean data, preserve it, provide access to the world, document the quality, and integrate data into information products. NODC is improving the data quality assurance, on-line access to remotely sensed and operational buoy data, and access and display of in-situ data and model simulations. The COL is focused on integrating coastal ocean data and information and providing on-line access to the world. COL is building an on-line FGDC Metadata Content Standard database for all of its global coastal ocean information. On-line users will be able to accurately retrieve metadata and quality assurance documentation. The Coast Watch Active Access System provides satellite data products and in-situ data from environmental buoys to on-line users. It includes AVHRR data, NOAA environmental buoy data, Ocean Color from SeaWifs, and coastal hazards data. The Interactive Data Access and Retrieval System (IDARS) was implemented to provide a Web based graphical user interface to allow visual browsing of data and model simulations. IDARS guides users through a simple querying procedure. After locating the desired data, the user may download the data from NODC's FTP server or order data on CD-ROMs. An interactive poster display will demonstrate the capabilities of these systems.

MIS-04: Estimation of the area of the coastal zone of the world

Eduardo Marone (maroneed@aica.cem.ufpr.br) and **Maurício Almeida Noernberg**, Centro de Estudos do Mar, UFPR, Pontal do Sul, PR, Brazil 83255-000

In this work, we performed a computational exercise in order to test the ability of the GEBCO 97 bathymetric atlas database to solve the area of the coastal zone of the world. GEBCO data were transformed from latitude and longitude to UTM horizontal co-ordinates, divided in 164 sub-databases. Over each of these subsets, different interpolation methods and grid sizes were applied, calculating the areas between the coastline and 50, 100 and 200 meters isobaths. Due to the scarcity of data around the Antarctic, this area was not included in the exercise. The resulting surface of the coastal zone of the world between the coastline and the 200 meters isobath ranged from less than 8% to more than 10% of the total earth's area. This variability is related to the interpolation method and the grid size used, but the lack of bathymetric data in several coastal zone areas seems to be the limiting factor. The scarcity of data in some coastal areas does not allow decreasing the grid size in any interpolation method, reducing the ability to solve for calculations that are more accurate. We concluded that it is not yet possible to use the database for coastal zone studies in a global scale. The lack of enough coverage reinforces the claim for the release and/or acquisition of bathymetric data in the coastal zone supporting the work of GEBCO developers.

MIS-05: Does UV-B intensity affect development of Pacific herring embryos?

Ricardo Lopez (fsrjl@aurora.alaska.edu), University of Alaska, Fairbanks, Fairbanks, Alaska 99775 USA

UV-B levels are increasing due to reductions in the ozone layer. Increased UV-B levels are linked to DNA damage and causes cancer and sunburns. Early embryonic stages of marine organisms are particularly sensitive to environmental factors. Using Pacific herring embryos, I studied the effects of UV-B exposure on developing eggs. UV-B significantly increases the percentage of dead eggs ($F=6.19$, $p=0.019$), but does not affect the time of hatching. However, UV damage is often sublethal and may become more evident over time.

MIS-06: The Health Benefits of Seal Oil

Lisa Ellanna-Brandt (nslle@aurora.alaska.edu), University of Alaska Fairbanks, Fairbanks, AK, 99775, USA

This presentation will consist of two basic qualitative studies done on rendered bearded seal oil, taken from the Northwest Alaskan coast. The purpose of this presentation is to examine the health benefits of seal oil and to test the hypothesis that seal oil may have antibiotic properties. The first study considered thke possible antibiotic properties seal oil may contain. Three oils were considered in this study; whale oil, soy oil and seal oil. Agar plates were smeared and bacterial and fungal growth were allowed for a period of (10) ten days. Seal oil showed considerably less growth than all other oils and control plates. This implies some antibiotic activity. The second study done consisted of the addition of 10% Bromine in dichloromethane (by weight) solution to test the level of saturation for the following oils: melted lard, olive oil and seal oil. In this study, seal oil proved to be the most polyunsaturated. The results of the above studies suggest that seal oil may have antibiotic activity and there is an indication that seal oil is highly polyunsaturated. Other properties of seal oil observed are: low viscosity and low freezing point. There is relevance to this topic considering the subsistence of marine mammals and fish by indigenous peoples of Alaska, Canada, Greenland and Siberia. There is also evidence that seal oil has been used in traditional medicine among the Inupiat of Northern Alaska. Elder testimony will be provided.

MIS-07: Fate of Zooxanthellae and Zoochlorellae after Passage Through the Gut of the Aeolid Nudibranch Aeolidia papillosa

Andrea M. Rocha, Texas A&M University - Corpus Christi, 6300 Ocean Dr., Corpus Christi, TX 78412, USA

The nudibranch, Aeolidia papillosa, consumes the sea anemone Anthopleura elegantissima, which contains algal symbionts. Both algal symbionts, zooxanthellae and zoochlorellae, pass through the gut of the predator. However, the effects of predation on the algae are unknown. Are the algae digested and is there a difference in the digestion of the two symbionts? Perhaps the ingestion and passage of algal pigments depend on whether they are in zooxanthellae or zoochlorellae. Anemones containing zooxanthellae (brown) and zoochlorellae (green) were fed to the nudibranchs and fecal pellets collected. A time lapse video camera was set up to record total passage time from ingestion to defecation. HPLC was used on fecal samples containing zooxanthellae and zoochlorellae to measure changes of pigments and I also measured assimilation effeciency. Gut passage times were 22 hours. Assimilation efficiencies of brown and green anemones were not significantly different. Pigments in the feces containing zooxanthellae and zoochlorellae were not significantly different from the pigments of algae in the host anemone. All of the results suggest that both zooxanthellae and zoochlorellae pass intact through the nudibranch gut. Since pigments and algae are passing through unharmed, both algal symbionts may benefit from dispersal in the nudibranch feces.

MIS-08: Arm Damage Effects on the Reproductive Energetics of the Six-rayed Seastar, Leptasterias hexactis

Omar J. Guerra (n9817093@cc.wwu.edu), Texas A&M University-Corpus Christi, 6300 Ocean Drive, Corpus Christi, Texas 78412 USA

The six-rayed seastar, common in the Puget Sound, WA, USA is often found with damaged or missing rays. To understand the cost of arm loss, I studied the relation between arm damage and the quality of the embryos the seastar produces. What consequences do embryos suffer as a result of arm damage? Brooding six-rayed seastars with arm damage were collected. Seastar dimensions, egg diameter, egg carbon content, and brood size data were collected. Undamaged and damaged seastars produced eggs that were similar in size, diameter and carbon content. However, brood sizes were smaller in seastars with arm damage. Arm damage in brooding Leptastarias hexactis forced energy distribution between arm regeneration and embryo energetics. Rather than sacrifice the quality of each egg, L. hexactis produces a smaller brood. This enables the seastar to devote more energy to individual embryos, increasing their chance of survival.

MIS-09: On the role of mesoscale eddies in the Japan Sea water mass transport and modification

Vyacheslav Lobanov (lobanov%dana1@poi.marine.su) (1), **Mikhail Danchenkov** (2), **Aleksandr Nikitin** (3) - (1) PacificOceanological Institute. 43 Baltiyskaya Street, Valdivostok 690041 Russia; (2) Far-Eastern Hydrometeorological Research Institute; (3) Pacific Research Institute of Fisheries and Oceanography, Vladivostok, Russia

The Sea of Japan has an active messoscale eddy field nested within the basin-scale circulation. While the eddies associated with a meandering of the Tsushima Warm Current and instabilities of the polar front are comparatively well known, stable anticyclonic eddies in the north-western part of the sea were just newly found. On the base of NOAA satellite infrared imagery for 1996-97 and historical hydrographic data it is demonatrated that the eddies have a life span of a few months (4 eddies were traced during 6 month and over) and general anti-clockwise translation over the western deep Japan Basin. Their diameters are within 50-100 km. A core of relatively fresh water (33.9-34.0 ppt) was found inside the eddies in a layer 50-200 m, which may originate from the northern coastal waters. Transporting fresh water down south to the polar front and stir their surroundings while translation the eddies are an important mechanism for redistribution of physical and biogeochemical properties. Active filamentation of the eddies and formation of streamers is another important factor for the basin-scale exchange. Being distributed over the entire basin the eddies form compact structures or eddy streets which provide more fast and effective mechanism of water exchange in the upper baroclinic layer in compare with the mean flow circulation.

MIS-10: Seasonal phytoplankton cycles in the contrasting ecosystems of the Black Sea

Z.Z. Finenko (verokhin@ ibss.iuf.net), Institute of Biology of the Southern Seas, 2 Nakhimov Ave, 335011, Sevastopol, Ukraine

The CZCS that operated aboard the Nimbus 7 satellite provided extensive coverage of chlorophyll-like concentrations in the surface waters of the Black Sea from 1979 to 1983. Seasonal phytoplankton dynamics for contrasting ecosystems was determined from CZCS pigment estimates. In coastal waters there is a long-term phytoplankton bloom in summer and a short one in autumn; in the deep waters there is long-term bloom in winter-spring period and a short one in early summer and autumn. A semi-analytical model has been developed to determine the primary production from satellite data of colour in the Black Sea. Historical data obtained during the last 20 years on the vertical chlorophyll a distribution (800 stations) and photosynthetic parameters of the phytoplankton (151 stations) were analysed and parameterised. The mathematical representation of the vertical profiles of chlorophyll, photosynthesis normalilized to chlorophyll biomass and statistical analyses on the parameters allowed the development of typical profiles for some delineated provinces in the sea, within each of which the spatial variability of the profile parameters was minimal for a given period of time (seasons). Development of semi-analytical algorithms have made it possible to describe in detail the seasonal periodicity of production cycles of phytoplankton.

MIS-11: Effect of environmental factors on phytoplankton photosynthesis in the Black Sea

T.I. Churilova (root@churil.sebastopol.ua), Institute of Biology of Southern Seas, P.O. 335011, box 13, Sevastopol, Crimea, Ukraine

Much research is currently being focused on estimations of primary production using the models which require parameterization of phytoplankton photophysiology. Present data describe in situ variability in physiological properties which are important for many bio-optical models of photosynthesis: the maximum photosynthesis (Pmax), the efficiency of photosynthesis (initial slope of the P versus I curve, achla). The environmental conditions such as light, temperature and nutrient availability have a large effect on the photophysiology of phytoplankton. Pronounced vertical stratification during summer created a sharp seasonal thermocline dividing the euphotic zone from the two separate layers with different environmental conditions. These layers differ in species composition of phytoplankton and photosynthetic properties. Summer values of P max ranged between 6.8 and 9.1 mgC.mgChla-1.h-1 for

near surface samples. These values were 2.1 - 3.5 mgC.mgChla-1.h-1 at the chlorophyll maximum near the bottom of the euphotic zone. The values of achla increased with depth from 0.017-0.019 to 0.028-0.042 mgC.mgChla-1.h-1. (μEin. m-2.s-1) -1. The seasonal thermocline dissipated during intense winter mixing and the mixed layer deepened down to 35-70m while the euphotic zone was within 18-27m range. Observed values of Pmax - 1.4 - 3.3 mgC.mgChla-1.h-1 and achla - 0.027-0.049mgC.mgChla-1.h-1. (μEin.m-2.s-1) -1 were uniformly distributed through the mixed layer indicating that photosynthetic properties did not vary with depth . Saturating light intensity was 40-88 μEin.m-2.s-1 which is typical for low light adapted phytoplankton.

MIS-12: Comparison of dynamics, biodiversity, and role of protozoa in an Atlantic coastal marsh and its adjacent tidal inlet

O. Robin and H.J. Hartmann, (hhartman@cri.univ.lr.fr), Laboratoire de Biologie et Biochimie Marine (LBBM), Université de La Rochelle, 17000 La Rochelle, France

To assess the role of microbial predators in a coastal marsh, the population dynamics of ciliates, and of autotrophic and heterotrophic flagellates in a monthly-flushed oyster- conditioning pond were compared with those of a neighboring tidal inlet of the Pertuis Breton in southwestern France. The inlet waters serve as inoculum for the pond. Over a three-month spring-summer season, distinctly different dynamic patterns in the two systems were observed. In the inlet, cell densities and biomasses were related to tidal dynamics, with peak values (ciliates: 1x10 4 cells/L and 35 μgC/L; flagellates 2x10 5 cells/mL and 5.9 μgC/L) observed during neap tides. Ciliate biomasses were negatively correlated with chlorophyll a. Biodiversities were consistently high, and no single taxon dominated for more than one week. In the pond, the communities grew exponentially to values exceeding inlet cell densities and biomasses by 1 to 2 orders of magnitude, and ciliate biomasses were positively correlated with chlorophyll a. Biodiversities were on average lower, declined over time, and evolved differently from those of the inlet. They were caracterized by a succession of several single dominant taxa (e.g. choreotrichs, oligotrichs and haptorids for ciliates). The results are discussed with regard to external and internal factors controlling the microbial dynamics in coastal marsh systems in general, and nutrition of large benthic filter feeders in particular.

POLICY AND LATEBREAKING EVENTS (POL)

POL-01: Complexity, Global Science and International Organizations

Patricio A. Bernal, Executive Secretary of the Intergovernmental Oceanographic Commission (IOC) of UNESCO, Paris, France

For the first time in history, modern civilization has reached a point at which direct and indirect effects are impacting natural systems all over the planet. This in turn has forced upon the scientific community the need to respond to a whole new set of emerging scientific and societal issues related to Global Change. These new issues are complex, challenging the traditional ways in which scientific inquiry is conducted. In doing this, scientists have had to develop new ways of organizing themselves in order to ensure appropriate and relevant targeting, secure missing information and to deliver timely responses. By being organized in autonomous institutions, scientists usually apply appropriate strategies to bridge the gaps in the knowledge base. However the demands and priorities of societies are expressed through different institutional channels that need to be monitored and reckoned with. Intergovernmental organizations provide fora in which these societal demands are directly expressed, processed and presented as relevant questions to the scrutiny of scientists; at the same time such organizations are the privileged source of advice for governments in the design of the necessary technical and scientific programs, beyond the limits of national jurisdiction; such decisions are a pre-requisite for governments before they can mobilize resources and commit themselves into international concerted action.

POL-02: Opportunity for Change with the Year of the Ocean

Stan Wilson (stan.wilson@noaa.gov), Deputy Chief Scientist, National Oceanic and Atmospheric Administration, 14th and Constitution Avenue, N.W., Washington, D.C. USA

The declaration of 1998 as the International Year of the Ocean by the United Nations presents an opportunity for countries to raise the visibility of ocean issues. This is a progress report on such efforts within the United States. We developed consensus among federal agencies regarding what was working well, what not well, and identifying opportunities and impediments. We partnered with the Heinz Center for Science, Economics and the Environment to incorporate representatives

from the private sector, academia, environmental groups, and state/local government. We are working with the White House on a National Ocean Conference for June 11/12, with the Vice President attending. We are encouraged by legislation pending in Congress--the Oceans Act--proposing to establish a National Ocean Commission, patterned after the Stratton Commission, whose 1969 recommendations led to create NOAA. We have seen significant increases in coastal population, development, environmental degradation, and exposure to natural hazards. At the same time, we cope with multiple jurisdictions, conflicting authorities, and agencies with a single-issue focus. We need an effective means for decision-making and priority-setting in managing our finite coastal and ocean resources. Over the past 15 years, we have seen our nation's investment in basic research for science double, while the comparable investment in ocean science grew by 1%! We need a new vision for the future of ocean S&T, one that recognizes the need for a sustainable future.

POL-03: Abrupt climate change and ocean circulation: Dynamical concepts and predictability

Jochem Marotzke (jochem@sound.mit.edu), Center for Global Change Science, Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139 USA

Abrupt climate changes occur faster than changes in the Earth's orbital parameters and arise from internal instabilities. Greenland ice core data reveal a rich history of climate changes occurring over a few decades. Recently, it has been prominently discussed in the popular press that enhanced greenhouse forcing might lead to rapid climate shifts. Reorganizations of the ocean's thermohaline circulation (THC) are generally assumed to be responsible for these changes. I will review the dynamical concepts underlying these arguments and discuss the THC's redictability. The THC exhibits multiple states of operation, owing to the interaction between high-latitude surface salinity and meridional transports of heat and salt. Thus, temporary perturbations can lead to a permanent reorganization of deep-water formation sites if a critical threshold is exceeded. This mechanism is shared by models of all levels of complexity, reaching from simple box models to global atmosphere-ocean general circulation models. In particular, the formation of North Atlantic Deep Water, the associated anomalously strong northward heat transport in the Atlantic, and the relatively mild climates around the North Atlantic are susceptible to rapid transitions. While the fundamental possibility of sudden changes is well established, the degree to which sudden THC changes in the Atlantic are predictable is unclear. Limits to predictability arise from chaotic elements in the climate system, unrealistic numerical models, and insufficient knowledge of the current oceanic state used to initialize prediction simulations. Examples are given for each of these categories, specifically: 1) The timing of a forced THC collapse may depend on details of atmospheric weather history; 2) "flux adjustments", artificial heat and freshwater sources at the air-sea interface, correct the mean climate in models but not the sensitivity of the THC; 3) initializations with available climatologies lead to rapid drifts in model solutions. We cannot with any degree of confidence assess the probability of a future THC collapse in the Atlantic. But the possibility clearly exists and the potential damage is huge, so a major research effort is warranted.

POL-04: Wheels within wheels or how local ecology drives ocean elemental cycles

Victor Smetacek (vsmetacek@awi-bremerhaven.de), Alfred Wegener Institute for Polar and Marine Research, Am Handelshafen 12, 27570 Bremerhaven, Germany

Since recent years our quantitative knowledge of ocean biogeochemical cycles and pelagic ecosystems is substantially improving. The time is now ripe for ocean scientists to seriously take up the challenge of explaining ocean biogeochemistry on the basis of the ecology and evolution of the key biota. This is a daunting task because the key elements C, O, N, P, Si, S, Fe have very different chemistries and hence sources and sinks. Their cycles are bound together by the workings of individual organisms such that local to basin-wide imbalances provide feedbacks that maintain global steady state on millenial scales. This appears fortuitous because of documented variability on decadal scales and the comparatively short turnover rates of the various elements. The ocean biota themselves pose some tantalising paradoxes such as phylogenetic diversity coupled with apparent species paucity and the dominant roles played by a few taxa. The concept of species needs to be critically examined in the light of the current debate on the issue of sex and the single cell because sexual phases can have profound biogeochemical implications. A better understanding of the relationships between form and function in the plankton will provide the causal framework for explaining elemental cycles. Finally, I shall argue that the Hindu symbol Trimurti is a more appropriate metaphor for planetary homoeostasis than the ancient earth goddess Gaia.

POL-05: EUROPEAN MARINE and POLAR SCIENCES(EMaPS) A European coordination in Marine and Polar Sciences

Daniel L. Cadet (daniel.cadet@cnrs-dir.fr), President EMAPS, CNRS3, 5 Rue Michel-Ange,75794 PARIS, Cedex 16, France

The establishment of EMaPS in 1995 resulted from the awareness of the scientific community and of the research organizations in Europe and of the European Commission of a need for a better coordination of activities within Europe. The main aims of EMaPS are to examine research issues of strategic importance for Europe, to facilitate the implementation of nternational research networks and projects of European dimension, to facilitate the shared use of research facilities, to promote joint activities in the development of new instrumentations and platforms for research and monitoring the marine and polar environment and to be a source of advice on science policy matters. The Marine Board includes 23 research organizations and the Polar Board 19 agencies as well as Directorate-General 12 of the Commission of the European Union. EMaPS is a tool in the hands of the research organizations and the scientific community. During the last three years, EMaPS has been active in promoting a European approach to ocean drilling (Position paper - European initiatives in science and technology for deep-sea coring and drilling), in defining a strategic plan on marine biodiversity (European science action plan on marine biodiversity), in developping scientific interactions on the issue of coastal management research (CISNET: Coastal Inter Sciences Network), in working out a research plan on ocean modelling linked to the objectives of EuroGOOS. Initiatives has also been taken to support shared use of marine research equipment, to support European Scientific Diving regulations, etc. The presentation will present the role of EMaPS within the framework of the 5th Framework Program of the Commission of the European Union.

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ABSTRACT TITLES

By order within session

Bold text indicates Chairs and Speakers.

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Policy and Late-Breaking Events

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*indicates first author

The Oceanography Societ

EXTREME AND UNEXPECTED

April 27–30, 1999 ❖

The meeting format will include morning plenary sessions of invited talks on daily session themes and poster abstracts in the afternoons focusing on, but not limited to, general theme and session topics. Commercial and educational exhibits will be co-located with the contributed posters. The registration fee will include daily continental breakfasts, morning and afternoon coffee breaks and an evening reception. Students are invited to attend and participate. Seventy-five (75) students will be permitted to register at half the regular registration fee. The half-price registrations will be allocated on a first-come basis. Some financial support will be available from the Scientific Committee on Ocean Research (SCOR) for oceanographers from developing countries; requests for this support must be received at TOS headquarters in writing by February 1, 1999.

The Reno/Lake Tahoe area offers a unique blend of attractions – a taste of the old West, big name entertainment and outstanding outdoor recreational opportunities. The Reno Hilton, a deluxe, full amenity hotel, has exceptional and varied dining, entertainment, shopping and recreation. Plan now to join your colleagues in "The Biggest Little City in the World" at the 1999 TOS meeting.

Call for Poster Abstracts

Poster Abstracts will be accepted November 15, 1998 through February 15, 1999 for review by the appropriate Session Chair. Abstract titles and content need not be specific to one of the broad session themes. Abstract acceptance notices will be issued no later than March 12, 1999. Every effort will be made to issue early notification to those who submit abstracts early.

Format

Abstracts are limited to 250 words, including title and author(s) name(s), affiliation(s) and address(es). An e-mail address for the first author is requested. Overly long abstracts will be returned for editing and will delay acceptance. Please align all text to the left margin.

PRELIMINARY PROGRAM

Meeting Program Chair: Thomas Kinder, Office of Naval Research

Tuesday, April 27

Session Topic: The Ocean in Commotion: Climate and Circulation Change on Long Time Scales

Session Chair: Lloyd Keigwin, Woods Hole Oceanographic Institution

Wednesday, April 28

Session Topic: From Sea Floor to the Sky: Biological Ramifications

Session Chair: Peter Franks, Scripps Institution of Oceanography

Q&A Session: Everything you want to know about the outlook for federal research funding and the exciting future of ocean science careers in the twenty-first century. An informal question and answer session for students and postdocs with federal agency leaders

David Evans, National Oceanic and Atmospheric Administration (NOAA)
Steve Ramberg, Office of Naval Research (ONR)
Mike Reeve, National Science Foundation (NSF)
Ken Turgeon, Minerals Management Service (MMS)
Jeff Williams, United States Geological Survey (USGS)

Thursday, April 29

Session Topic: Geological Perturbations and Consequences

Session Chair: James Syvitski, University of Colorado

Q&A Session: Same as Wednesday Q&A session, open to all meeting attendees

Friday, April 30

Session Topic: Technology and More

Session Chair: Thomas Kinder, Office of Naval Research

1999 Scientific Meeting

PHENOMENA IN THE OCEAN

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Submissions

Electronic mail is the preferred method for submitting abstracts and will ensure the fastest review. Abstracts may also be submitted via facsimile, mail or other delivery service for an additional charge.

E-mail submissions: **Send to both** (1) TOS Meeting Planning Office (J.Rhodes@tos.org) with credit card information and indication to which daily topic the abstract is related and (2) the Chairperson of the session to which your abstract relates or the Program Chair, if unrelated to any of the daily topics. **Submit text files only -- no attachments of any kind.** (E-mail addresses shown are only good for the TOS meeting.)

Session Chairs:
Day 1: Lloyd Keigwin (L.Keigwin@tos.org)
Day 2: James Syvitski (J.Syvitski@tos.org)
Day 3: Peter Franks (P.Franks@tos.org)
Day 4: Thomas Kinder (T.Kinder@tos.org)

Program Chair: Thomas Kinder

Facsimile submissions: Send to TOS Meeting Planning Office (757/464-1759) with credit card information.

Abstract Fees

The fee is US$ 65 (US$ 35 for students) for abstracts submitted by e-mail or US$ 75 (US$ 40 for students) for those submitted by any other means. Payment must be made at the time the abstract is submitted. Electronic and facsimile submissions must be paid by credit card (Visa or Mastercard only); mail or delivery service submissions may be paid with check, money order or credit card. TOS is unable to process training or purchase orders and cannot issue invoices for payment. Fees for abstracts that are not accepted will be refunded. Fees for abstracts that are withdrawn no later than March 1, 1999 will also be refunded. Revisions to submitted abstracts are discouraged; revised abstracts will be treated as new submissions and the applicable fee will again be charged.

Abstract Publication

The meeting program and abstracts will be published as an issue of the TOS publication, *Oceanography*, and may be cited after the meeting.

Meeting Registration

All participants, including poster presenters, must register for the meeting. Registration forms and details are included in this issue of the magazine, on the TOS web site (http://www.tos.org) and in direct-mail brochures.

Hotel Accommodations

The Reno Hilton will serve as the headquarters hotel and is offering TOS meeting participants the special rate of US$ 85, plus tax. Seventy-five (75) rooms are also being offered to federal government employees at US $57, including tax, (government ID must be presented at check-in). Make your reservations by calling Hilton's toll-free number (800/648-5080) or by writing to: Reno Hilton, Reservations Department, 2500 East Second Street, Reno, NV 89595. Credit card information is required to guarantee your reservation. Be certain to identify yourself as attending The Oceanography Society meeting. Basic changes or cancellations may be made up to 24-hours prior to scheduled arrival.

Information Updates

Check the TOS web site (http://www.tos.org) and printed brochures for additional information as it develops, or contact the TOS Meeting Planning Office, 4052 Timber Ridge Drive, Virginia Beach, VA 23455 USA; (757) 464-0131; FAX: (757) 464-1759; e-mail: (J.Rhodes@tos.org).

ADVANCE REGISTRATION FORM

The Oceanography Society 1999 Scientific Meeting

EXTREME AND UNEXPECTED PHENOMENA IN THE OCEAN

April 27-30, 1999 ❖ Reno Hilton · Reno, Nevada

(Please print clearly.)

Name (for badge) _____

Institution (for badge) _____

Address _____

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A Spouse/Guest badge will be necessary for admission to the evening reception for those not registered for the meeting.

Spouse/Guest Name: _____

I am a member of the following sponsoring or co-sponsoring organization(s) and entitled to registration at the TOS member rate:

❍ TOS ❍ AGU ❍ AMS ❍ ASLO ❍ CMOS ❍ CSMS ❍ MTS ❍ SCOR

Days attending: ❍ Tuesday ❍ Wednesday ❍ Thursday ❍ Friday

Advance Registration Fee: Registration form, with payment, must be received by TOS by March 26, 1999. Registration after March 26 must be done in Reno at the on-site rate. (Check applicable fee category below.)

Full Meeting	❍ TOS member US$ 250	❍ TOS student member US$ 125
	❍ Non-member US$ 300*	❍ Non-member student US$ 150*
One Day Only	❍ TOS member US$ 75	❍ TOS student member US$ 40
	❍ Non-member US$ 125*	❍ Non-member student US$ 65*

* Includes TOS membership, if membership application is completed and returned at the meeting.

TOTAL REGISTRATION FEE: US$ _____

❍ My check payable to The Oceanography Society (in US$, drawn on a U.S. bank) is enclosed OR

❍ Charge my credit card:

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THE OCEANOGRAPHY SOCIETY
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THE OCEANOGRAPHY SOCIETY

The Oceanography Society was founded in 1988 to disseminate knowledge of oceanography and its application through research and education to promote communication among oceanographers, and to provide a constituency for consensus-building across all the disciplines of the field. The Oceanography Society is a non-profit, tax-exempt organization incorporated in the District of Columbia.

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Regular membership is available to oceanographers, scientists, or engineers active in ocean-related fields, or persons who have advanced oceanography by management or other public service. With proper certification, Student membership is available for students enrolled at least half-time in an oceanography or ocean-related program at the baccalaureate or higher level. Sponsoring membership is available to individuals who wish to provide enhanced support annually. In the United States, US$ 50 of the annual dues in this category is tax-deductible as a charitable contribution, as are any additional contributions, over and above the annual Regular Member dues. Organizations and companies may subscribe annually as Corporate/Institutional Members. Annual library subscriptions are also available. All members are entitled to exercise the rights and responsibilities of active participation in the Society, including the vote. All members receive *Oceanography*. All applications for membership are subject to approval by the Membership Committee of the Society. To join, fax (202) 265-4409 or mail the application with completed information and appropriate payment to:

THE OCEANOGRAPHY SOCIETY
1755 Massachusetts Ave NW, Suite 700
Washington, DC 20036 USA

APPLICATION

Please accept my application for membership in The Oceanography Society. My annual membership dues will support the work of the Society and will entitle me to receive *Oceanography*, to register at discounted rates for meetings sponsored and/or co-sponsored by the Society, to vote in Society elections, and to express my opinion on all matters of interest to the Society.
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Style Guide and Information for Contributors

Philosophy: *Oceanography* exists to promote and chronicle all aspects of ocean science and its applications. It publishes brief articles, critical essays and concise reviews that deal with topics of broad interest to the ocean-science community. In addition, *Oceanography* solicits and publishes news and information, meeting reports, book reviews, and other items of current interest.

Manuscript Requirements: All manuscripts must be typewritten and double spaced. Manuscripts must include the title, name and affiliation (including city, state and zip code) of each author. Acknowledgments, references and figures should follow the stylistic conventions outlined below. Please submit four hard copies of the manuscript and a copy on disk (indicating software used) to:

Dr. Richard W. Spinrad
Consortium for Oceanographic Research and Education (CORE)
1755 Massachusetts Avenue NW, Suite 800
Washington, DC 20036 USA

Submitted material will be reviewed for style, relevance and quality by the editors and by anonymous external reviewers.

Language Style: The desired style of writing is less technical and more compact than that typically used in scientific papers. The readership includes oceanographers from all traditional disciplines, as well as scientifically literate persons with a broad range of interests and responsibilities. Authors should strive for clarity and simplicity and avoid technical and mathematical jargon. Perhaps the best description of the expected style is the following.

> Vigorous writing is concise. A sentence should contain no unnecessary words, a paragraph no unnecessary sentences, for the same reason that a drawing should have no unnecessary lines and a machine no unnecessary parts. This requires not that the writer make all his sentences short, or that he avoid all detail and treat his subjects only in outline, but that every word tell.

William Strunk, Jr. and E. B. White The Elements of Style, third ed., © 1979 Macmillan Pub. Co., Inc. Reprinted with permission.

Length Limitations: (Maximum length of articles must be strictly followed):

- **Feature Articles:**
  10-12 double-spaced, typed pages; 4-5 figures.
- **Review and Comment Pieces:**
  5-8 pages, 2-3 figures.
- **Other** (e.g., News and Information, Meeting and Workshop Reports, or Book Reviews) should be as concise as possible. Meeting reports should describe goals, activities and accomplishments; not agendas, programs and attendance.

References: *Oceanography* does not use numbered footnotes. Instead, textual references should be given parenthetically as: (author, year). Complete and correct references are the author's responsibility. A complete list of references should be ordered alphabetically by the first author's last name, and placed at the end of the manuscript in following format.

- **Article in Journal:**

Author(s), year: Title of article. *Title of Journal* (abbreviated), volume number, inclusive pages.

Example:

Levin, M.E., 1979: Ahab as Socratic philosopher: The Myth of the Cave inverted. *Am. Transcendental Quar.*, 41, 61-73.

- **Article in Book:**

Author(s), year: Title of article. In: *Title of Book*. Editor's name, ed., publisher, city, inclusive pages.

Example:

Skirrow, G., 1975: The dissolved gases-carbon dioxide. In: *Chemical Oceanography*, vol. 2, 2nd edition. J.P. Riley and G. Skirrow, eds., Academic Press, New York, 1-192.

- **Book:**

Author(s), year: *Title of Book*. Publisher, city, total pages.

Example:

Baker, B.B. and E.T. Copson, 1939: *The Mathematical Theory of Huygens' Principle*. Clarendon, Oxford, 155 pp.

• **Thesis:**

Author, year: Name of thesis. Masters/PhD. thesis, name of university, total pages.

Example:

Rintoul, S., 1988: Mass, heat and nutrient fluxes in the Atlantic Ocean determined by inverse methods. Ph.D. thesis, Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program, 287 pp.

• **Proceedings:**

Author(s), year: Name of report. In: *Name of Proceedings*. Name of conference, publisher, city, inclusive pages.

Example:

Knauss, J.A. and M.H. Katsouros, 1986: Recent experiences of the United States in conducting marine scientific research in coastal state Exclusive Economic Zones. In: *The Law of the Sea: What Lies Ahead?* Proceedings of the Twentieth Annual Conference on the Law of the Sea Institute, 1986, Univ. of Hawaii Press, Honolulu, 297-309.

Abbreviations should conform to the current Chemical Abstracts Service Source Index published by The American Chemical Society, or see the American Meteorological Society's Author's Guide. Articles that have been accepted for publication may be cited, if the journal name and volume number are provided in the list of references. "In press" citations are acceptable. The correct citation for this publication is *Oceanography.*

Figures/Tables: Each figure or table should be accompanied by a complete caption and be cited and explained in the text. All figures and drawings should be of exceptional quality to allow for clear reproduction and reduction. Articles generally are limited to four or five figures. Review and Comment pieces generally are limited to three figures. Line drawings and black-and-white or color photos are acceptable; authors must pay the additional costs of color processing.

Units: The International System (SI) should be used throughout. Symbols for a unit of measurement should be used only when preceded by a number (e.g. "10 m" but "several meters"). Unit symbols are not to be punctuated (i.e., they are not treated as abbreviations); the same symbol is used for both singular and plural.

Abbreviations: Abbreviations and acronyms must be identified with their first use. The solitary use of acronyms is unnecessary and discouraged. The abbreviation "U.S." is appropriate when it modifies another word (e.g. U.S. Department of Commerce). Names of states and months should be spelled out except in Table and Reference sections.

Mathematical Formulas: The use of mathematical symbols and formulas should be held to the absolute minimum necessary, and in those cases all symbols must be clearly defined in the text. For detailed guidelines, see the Author's Guide of the American Meteorological Society.

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Book/Video Reviews: Reviews are solicited for scientific books and videos, and also for published material with a potentially wider appeal (e.g., novels, biographies, historical anecdotes. etc.). Reviewed material must have relevance to the oceans. Reviewers should keep in mind that a well-written review helps readers decide whether or not it is worth their time to read the book in its entirety. The reader of a review expects basic information about the content and organization of the book, as well as a subjective opinion about the quality, style and relevance of the material.

Reviews should include: complete title of book/video, author or editor, year of publication, number of pages, price, format (hardbound, softcover, paperback, etc.), name of publisher, city of publication and the reviewer's name, title and affiliation.

Reprints: Offprints of published articles are offered at the time of acceptance and are printed concurrently with the magazine. Contact the editorial office for current estimates of reprint costs.

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DIALOG III

Dissertations Initiative for the Advancement of Limnology and Oceanography

Program for Recent Ph.D. Recipients in Limnology, Oceanography and Related Disciplines

PURPOSE

The DIALOG (Dissertations Initiative for the Advancement of Limnology and Oceanography) program seeks to reduce the historical, institutional and philosophical barriers that limit the exchange of information among aquatic scientists, and to expedite the transition from Ph.D. student to independent researcher. Through this program, the dissertation abstracts of program participants are collected and made available, and a symposium is held to foster interdisciplinary thinking and collaborations. In addition, information on recent Ph.D. recipients is collected for human-resources purposes.

DATABASE

Information submitted by applicants is used to characterize this most recent group of Ph.D. recipients, and later, as the data base expands, will be used to assess trends. Follow-up studies will be conducted to assess professional progress of participants and long-term outcomes of the program.

Ph.D. ABSTRACTS

Dissertations abstracts are compiled and made available through the ASLO web page (http://www.aslo.org/dialog.html) to provide a concise introduction to the work of this most recent generation of aquatic science researchers. Abstracts from dissertations completed after April 1, 1997 are eligible for inclusion. Application for the DIALOG III symposium is not necessary.

SYMPOSIUM

A symposium for up to 40 recent Ph.D. recipients will be held in October, 1999 to foster cross-disciplinary and international understanding and collaborations. Each participant will present a poster and a 10-minute overview of his or her Ph.D. dissertation research, with an additional 5 minutes for questions/discussion. Participants will also form working groups to discuss emerging aquatic science research, education, and policy issues. Funding-agency representatives will present perspectives on interdisciplinary and international aquatic science research programs and building a successful career. Symposium travel subsidies are possible through funding from the agencies listed below. Support from the European Commission is pending.

Symposium Eligibility

The symposium is open to individuals who complete their Ph.D. requirements between April 1, 1997 and March 31, 1999, and whose work in atmospheric, biological, chemical, geological, physical or terrestrial science is relevant to biologically oriented limnology or oceanography. Individuals from all nations are eligible for consideration. A committee will select participants based on the application materials submitted. As symposium space is expected to be limited, selection will favor those who wish to pursue interdisciplinary aquatic science research.

Symposium Dates and Location

October 18-24, 1999
Bermuda Biological Station
for Research

Symposium Application Deadline

May 1, 1999

APPLICATIONS

Dissertation abstract-submission and symposium-application forms are available at:

http://www.aslo.org/dialog.html

Questions

Susan Weiler/DIALOG
Whitman College
Walla Walla, WA 99362 USA
Tel: 509-527-5948
Fax: 509-527-5961
E-mail: aslo.dialog@whitman.edu

DIALOG is co-sponsored by the American Society of Limnology and Oceanography and Whitman College, and is funded by the U.S. National Science Foundation, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, and Office of Naval Research.

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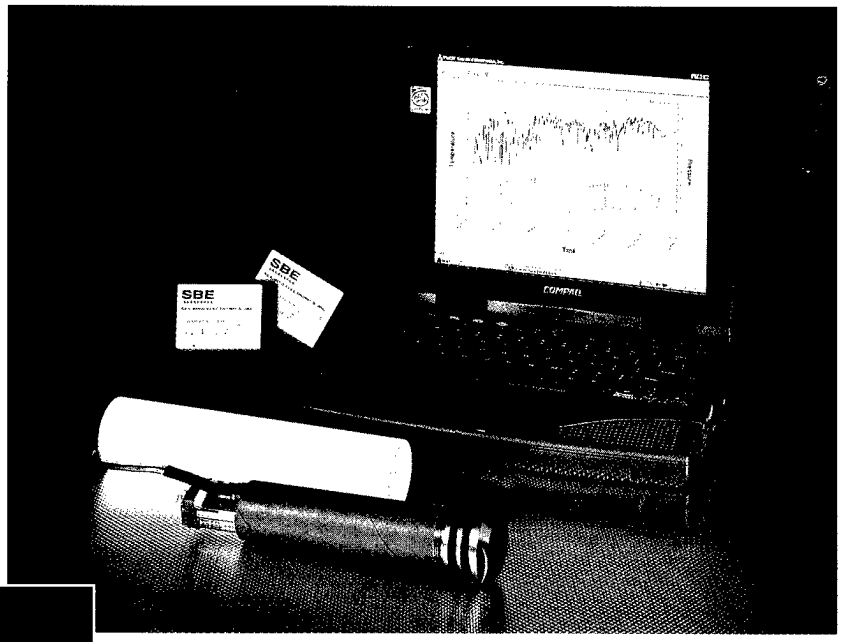

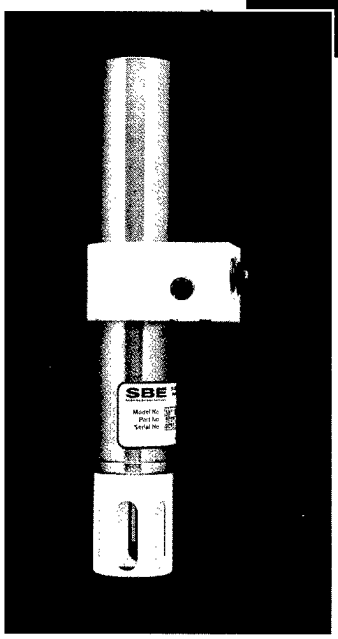

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